19 WATER POLLUTION

Learning Nature's Ways to Purify Sewage

Some communities and individuals are seeking better ways to purify sewage by working with nature. Ecologist John Todd designs, builds, and operates innovative ecological wastewater treatment systems called *living machines* (Figure 19-1). They look like aquatic botanical gardens and are powered by the sun in greenhouses or outdoors, depending on the climate.

This ecological purification process begins when sewage flows into a passive solar greenhouse or outdoor site containing rows of large open tanks populated by an increasingly complex series of organisms. In the first set of tanks, algae and microorganisms decompose organic wastes into nutrients that are taken up by aquatic plants such as water hyacinths, cattails, and bulrushes.

In these tanks, algae and microorganisms decompose wastes into nutrients absorbed by the plants. The decomposition is speeded up by sunlight.

After flowing though several of these natural purification tanks, algae and organic waste are filtered out as the water passes through an artificial marsh of sand, gravel, and bulrush plants. Some of the plants also absorb (sequester) toxic metals such as lead and mercury and secrete natural antibiotic compounds that kill pathogens.

Next the water flows into engineered ecosystems in aquarium tanks, where snails and zooplankton consume microorganisms and are in turn consumed by crayfish, tilapia, and other fish that can be eaten or sold as bait. After 10 days, the clear water flows into a second artificial marsh for final filtering and cleansing.

The water can be made pure enough to drink by using ultraviolet light or passing the water through an ozone generator, usually immersed out of sight in an attractive pond or wetland habitat. The chief byproducts of such living machines are ornamental plants, trees, and baitfish that can be sold. Operating costs are about the same as for a conventional sewage treatment plant.

This technology is sold by Living Technologies, which has installed 30 living machine purification systems in the United States and six other countries, including the system for the innovative environmental science building at Oberlin College in Ohio (Figure 15-24, p. 376). Some communities and industries are working with nature by using natural and artificial wetlands to purify waste water, as discussed on p. 496.

Water pollution is related to air pollution, land-use practices, climate change, and the number of people, farms, and industries producing sewage. These connections explain why solving water pollution problems should be integrated with air pollution, energy, land-use, climate, and population policies that emphasize pollution prevention. Otherwise, we will continue shifting potential pollutants from one part of the biosphere to another until threshold levels of damage are exceeded as more people, farms, and industries produce more wastes.

Figure 19-1 Ecological wastewater purification by a *living machine.* At the Providence, Rhode Island, Solar Sewage Treatment Plant, biologist John Todd demonstrates how ecological waste engineering in a greenhouse can be used to purify wastewater in an ecological process he invented. Todd and others are conducting research to perfect solar-aquatic sewage treatment systems based on working with nature. (Ocean Arks International)

Today everybody is downwind or downstream from somebody else.

William Ruckelshaus

This chapter addresses the following questions:

- What pollutes water, where do the pollutants come from, and what effects do they have?
- What are the major water pollution problems of streams and lakes?
- How is groundwater polluted, and what can be done to prevent such pollution?
- What are the major water pollution problems of oceans?
- How can we prevent and reduce surface-water pollution?
- How safe is drinking water, and how can it be made safer?

19-1 TYPES AND SOURCES OF WATER POLLUTION

What Are the Major Water Pollutants, and How Do We Detect Them? **Water pollution** is any chemical, biological, or physical change in water quality that has a harmful effect on living organisms or makes water unsuitable for desired uses. Table 19-1 lists the major classes of water pollutants along with their major human sources and harmful effects. Table 19-2 lists some common diseases that can be transmitted to humans through drinking water contaminated with infectious agents.

Various methods are used to determine water quality. A good indicator of water quality in terms of infectious agents is the number of colonies of *coliform bacteria* present in a 100-milliliter (0.1-quart) sample of water. The World Health Organization recommends a coliform bacteria count of 0 colonies per 100 milliliters for drinking water, and the U.S. Environmental Protection

Table 19-1 Major Categories of Water Pollutants States

Infectious Agents
Examples: Bacteria, viruses, protozoa, and parasitic worms
Major Human Sources: Human and animal wastes
Harmful Effects: Disease (Table 19-2)

Oxygen-Demanding Wastes
Examples: Organic waste such as animal manure and plant debris that can be decomposed by aerobic (oxygen-requiring) bacteria
Major Human Sources: Sewage, animal feedlots, paper mills, and food processing facilities
Harmful Effects: Large populations of bacteria decomposing these wastes can degrade water quality by depleting water of dissolved oxygen. This causes fish and other forms of oxygen-consuming aquatic life to die.

Inorganic Chemicals
Examples: Water-soluble **(1)** acids, **(2)** compounds of toxic metals such as lead (Pb), arsenic (As), and selenium (Se), and **(3)** salts such as NaCl in ocean water and fluorides (F^-) found in some soils
Major Human Sources: Surface runoff, industrial effluents, and household cleansers
Harmful Effects: Can **(1)** make freshwater unusable for drinking or irrigation, **(2)** cause skin cancers and crippling spinal and neck damage (F^-), **(3)** damage the nervous system, liver, and kidneys (Pb and As), **(4)** harm fish and other aquatic life, **(5)** lower crop yields, and **(6)** accelerate corrosion of metals exposed to such water.

Organic Chemicals
Examples: Oil, gasoline, plastics, pesticides, cleaning solvents, detergents
Major Human Sources: Industrial effluents, household cleansers, surface runoff from farms and yards
Harmful Effects: can **(1)** threaten human health by causing nervous system damage (some pesticides), reproductive disorders (some solvents) and some cancers (gasoline, oil, and some solvents) and **(2)** harm fish and wildlife

Plant Nutrients
Examples: Water-soluble compounds containing nitrate (NO_3^-), phosphate (PO_4^{3-}), and ammonium (NH_4^+) ions
Major Human Sources: Sewage, manure, and runoff of agricultural and urban fertilizers
Harmful Effects: Can cause excessive growth of algae and other aquatic plants which die, decay, deplete water of dissolved oxygen, and kill fish. Drinking water with excessive levels of nitrates lowers the oxygen-carrying capacity of the blood and can kill unborn children and infants ("blue-baby syndrome").

Sediment
Examples: Soil, silt
Major Human Sources: Land erosion
Harmful Effects: Can **(1)** cloud water and reduce photosynthesis, **(2)** disrupt aquatic food webs, **(3)** carry pesticides, bacteria, and other harmful substances, **(4)** settle out and destroy feeding and spawning grounds of fish, and **(5)** clog and fill lakes, artificial reservoirs, stream channels, and harbors.

Radioactive Materials
Examples: Radioactive isotopes of iodine, radon, uranium, cesium, and thorium
Major Human Sources: Nuclear power plants, mining and processing of uranium and other ores, nuclear weapons production, natural sources
Harmful Effects: Genetic mutations, miscarriages, birth defects, and certain cancers

Heat (Thermal Pollution)
Examples: Excessive heat
Major Human Sources: Water cooling of electric power plants (Figure 14-32, p. 346) and some types of industrial plants. Almost half of all water withdrawn in the United States each year is for cooling electric power plants.
Harmful Effects: Lowers dissolved oxygen levels and makes aquatic organisms more vulnerable to disease, parasites, and toxic chemicals. When a power plant first opens or shuts down for repair, fish and other organisms adapted to a particular temperature range (Figure 4-14, p. 79) can be killed by the abrupt change in water temperature—known as *thermal shock.*

Table 19-2 Common Diseases Transmitted to Humans Through Contaminated Drinking Water

Type of Organism	Disease	Effects
Bacteria	Typhoid fever	Diarrhea, severe vomiting, enlarged spleen, inflamed intestine; often fatal if untreated
	Cholera	Diarrhea, severe vomiting, dehydration; often fatal if untreated
	Bacterial dysentery	Diarrhea; rarely fatal except in infants without proper treatment
	Enteritis	Severe stomach pain, nausea, vomiting; rarely fatal
Viruses	Infectious hepatitis	Fever, severe headache, loss of appetite, abdominal pain, jaundice, enlarged liver; rarely fatal but may cause permanent liver damage
Parasitic protozoa	Amoebic dysentery	Severe diarrhea, headache, abdominal pain, chills, fever; if not treated can cause liver abscess, bowel perforation, and death
	Giardiasis	Diarrhea, abdominal cramps, flatulence, belching, fatigue
Parasitic worms	Schistosomiasis	Abdominal pain, skin rash, anemia, chronic fatigue, and chronic general ill health

Agency (EPA) recommends a maximum level for swimming water of 200 colonies per 100 milliliters.

Water pollution from oxygen-demanding wastes and plant nutrients can be determined by measuring the level of dissolved oxygen (Figure 19-2). The quantity of oxygen-demanding wastes in water can be determined by measuring the **biological oxygen demand (BOD)**: the amount of dissolved oxygen needed by aerobic decomposers to break down the organic materials in a certain volume of water over a 5-day incubation period at 20°C (68°F).

Chemical analysis is used to determine the presence and concentrations of most inorganic and organic chemicals that pollute water. Living organisms can also be used as *indicator species* to monitor water pollution. For example, the tissues of *filter-feeding mussels*, harvested from the sediments of coastal waters, can be analyzed for the presence of various industrial chemicals, toxic metals (such as mercury and lead), and pesticides. Aquatic plants such as cattails can be removed and analyzed to determine pollution in areas contaminated with fuels, solvents, and other organic chemicals.

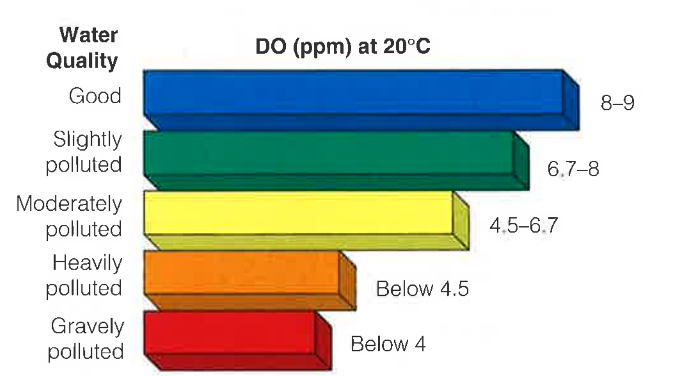


Figure 19-2 Water quality and dissolved oxygen (DO) content in parts per million (ppm) at 20°C (68°F). Only a few fish species can survive in water with less than 4 ppm of dissolved oxygen at this temperature.

What Are Point and Nonpoint Sources of Water Pollution? **Point sources** discharge pollutants at specific locations through pipes, ditches, or sewers into bodies of surface water. Examples include **(1)** factories, **(2)** sewage treatment plants (which remove some but not all pollutants), **(3)** active and abandoned underground mines, and **(4)** oil tankers. Because point sources are at specific places, they are fairly easy to identify, monitor, and regulate. In developed countries many industrial discharges are strictly controlled, whereas in most developing countries such discharges are largely uncontrolled.

Nonpoint sources are sources that cannot be traced to any single site of discharge. They are usually large land areas or airsheds that pollute water by runoff, subsurface flow, or deposition from the atmosphere. Examples include runoff of chemicals into surface water from croplands, livestock feedlots, logged forests, urban streets, lawns, golf courses, and parking lots and acid deposition (Figure 17-9, p. 428).

Nonpoint pollution from agriculture includes sediments, inorganic fertilizers, manure, salts dissolved in irrigation water, and pesticides. In the United States, such pollution is responsible for an estimated 64% of the total mass of pollutants entering streams and 57% of those entering lakes. Little progress has been made in controlling nonpoint water pollution because of the difficulty and expense of identifying and controlling discharges from so many diffuse sources.

19-2 POLLUTION OF STREAMS AND LAKES

What Are the Pollution Problems of Streams? Flowing streams, including large ones called *rivers*, can recover rapidly from degradable, oxygen-demanding wastes and excess heat by a combination of dilution

and bacterial decay. This natural recovery process works as long as **(1)** streams are not overloaded with these pollutants and **(2)** their flow is not reduced by drought, damming, or diversion for agriculture and industry. However, these natural dilution and biodegradation processes do not eliminate slowly degradable and nondegradable pollutants.

In a flowing stream, the breakdown of degradable wastes by bacteria depletes dissolved oxygen, which reduces or eliminates populations of organisms with high oxygen requirements until the stream is cleansed of wastes. The depth and width of the resulting *oxygen sag curve* (Figure 19-3), and thus the time and distance needed for a stream to recover, depend on the volume of incoming degradable wastes and the stream's **(1)** volume, **(2)** flow rate, **(3)** temperature, and **(4)** pH level (Figure 3-7, p. 56). Similar oxygen sag curves can be plotted when heated water from industrial and power plants is discharged into streams.

What Progress Have We Made in Reducing Stream Pollution? Requiring cities to withdraw their drinking water downstream rather than upstream (as is done now) would improve water quality dramatically. Then each city would be forced to clean up its own waste outputs rather than passing them downstream. However, upstream users, who already have the use of fairly clean water without high cleanup costs, fight this pollution prevention approach.

Here is some *good news*. Water pollution control laws enacted in the 1970s have greatly increased the number and quality of wastewater treatment plants in the United States and many other developed countries. Laws have also required industries to reduce or eliminate point-source discharges into surface waters. These efforts have enabled the United States to hold the line against increased pollution of most of its streams by disease-causing agents and oxygen-demanding wastes. This is an impressive accomplishment given the rise in economic activity and population since the laws were passed.

One success story is the cleanup of Ohio's Cuyahoga River, which was so polluted that in 1959 and again in 1969 it caught fire and burned for several days as it flowed through Cleveland, Ohio. The highly publicized image of this burning river prompted city, state, and federal officials to **(1)** enact laws limiting the discharge of industrial wastes into the river and sewage systems and **(2)** appropriate funds to upgrade sewage treatment facilities. Today the river has made a comeback and is widely used by boaters and anglers.

Pollution control laws passed since 1970 have also led to improvements in dissolved oxygen content in

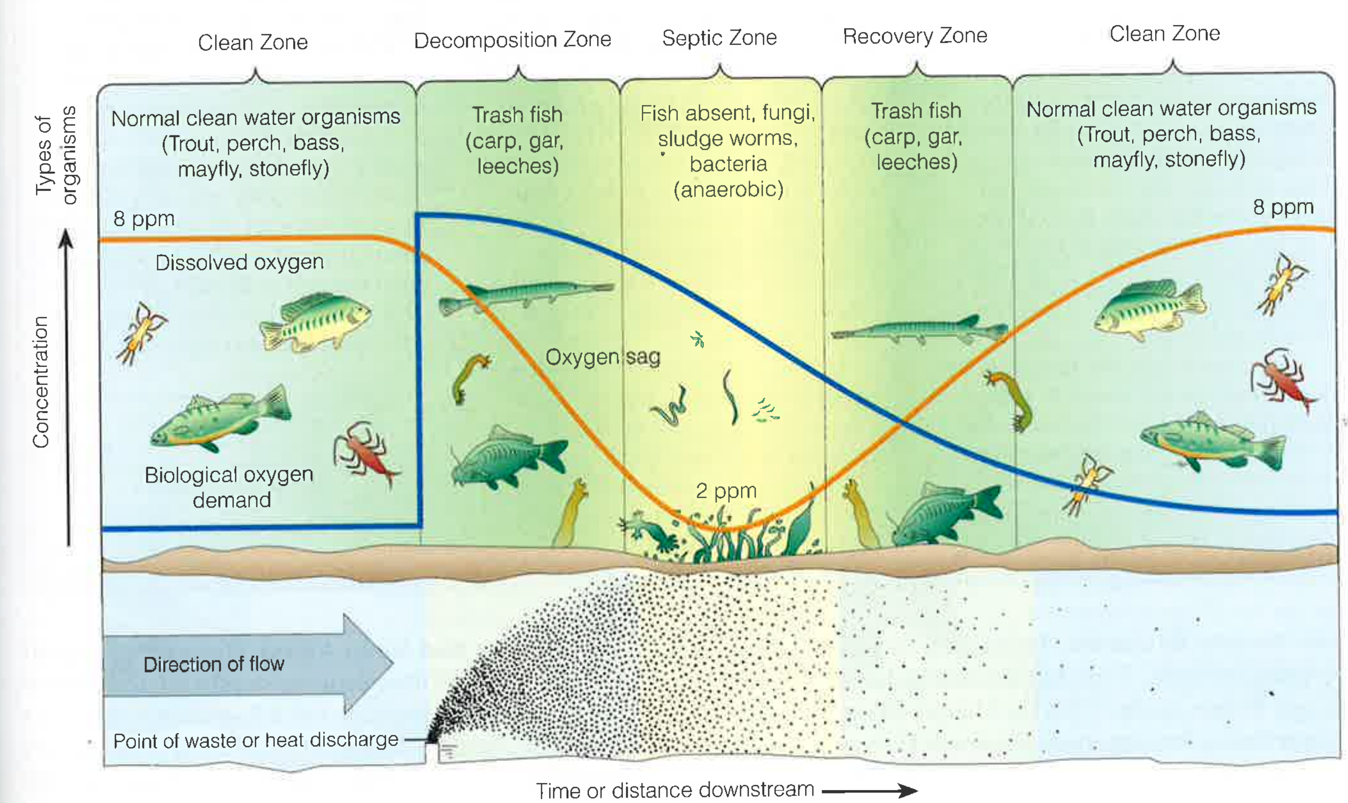


Figure 19-3 Dilution and decay of degradable, oxygen-demanding wastes and heat, showing the oxygen sag curve (orange) and the curve of oxygen demand (blue). Depending on flow rates and the amount of pollutants, streams recover from oxygen-demanding wastes and heat if they are given enough time and are not overloaded.

INDIVIDUALS MATTER

Tracking Down the *Pfiesteria* Cell from Hell

JoAnn M. Burkholder is professor of aquatic biology and marine science at North Carolina State University. She knows what it is to be sickened by a newly identified fish-killing microbe and to experience the political heat when you go public with your research to alert people about a potentially serious health threat.

In 1986, she investigated why a colleague's laboratory research fish were dying mysteriously and discovered that the culprit was a new microbe so tiny that dozens could fit on the head of a pin. She and her codiscoverer named it *Pfiesteria piscida* (pronounced "fee-STEER-e-ah pis-kuh-SEED-uh"), but some biologists call it the cell from hell.

She and her colleagues discovered that this complex microscopic organism could behave as both a plant and an animal and assume at least 24 guises in its lifetime. Without suitable prey, the microbe can masquerade as a plant or lie dormant for years. Then under certain conditions these microbes can change from alga eaters into fish-killing dinoflagellates that **(1)** release neurotoxins that stun fish in rivers and coastal estuaries and **(2)** usually kills them within 10 minutes to several hours.

The neurotoxin can also form an aerosol above the water. In 1993, Burkholder and her chief research aid experienced nausea, burning eyes and cramps, weakness, slow-healing sores, difficulty breathing, and severe loss of memory and mental powers from breathing toxic fumes released in tanks of fish dying from *Pfiesteria* attacks. They eventually recovered but still cannot exercise strenuously without severe shortness of breath and the onset of respiratory illness.

Since then more than 100 researchers, fishermen, and water-skiers in North Carolina, Virginia, and Maryland have experienced one or more of these symptoms when exposed to water or air contaminated by *Pfiesteria* toxins. In 1995, Burkholder and her colleagues detected a second species of fish-eating *Pfiesteria* in North Carolina's New River after a major spill from a hog-waste lagoon. These single-cell organisms live in waters from the Chesapeake Bay to the Gulf Coast of Florida and Alabama and each year cause more than $60 million in losses to U.S. fisheries and tourism.

Through lab and field research, Burkholder developed evidence that connected outbreaks or blooms of *Pfiesteria* with excessive levels of nitrogen (as nitrates) and phosphorus (as phosphates) in rivers and estuaries. High levels of such nutrients are found in runoff from fertilized croplands, industrial development, and feedlots (especially those used to raise hogs and chickens) into rivers flowing into coastal estuaries.

In 1991, Burkholder went public with her findings and urged North Carolina state legislators to put curbs on hog farming and enact much tougher laws to reduce the flow of nutrients and other pollutants into the state's rivers. Hog farmers, developers, farming interests, fishing industry officials (worried about whether it is safe to eat fish and shellfish from affected rivers and estuaries), tourist industry officials (alarmed about a negative image of the state's huge coastal recreational industry), and some state officials reacted negatively to her political activism. Some challenged her character and competence and accused her of using the results of preliminary research to push for questionable policies. She also received some anonymous death threats.

Burkholder has not backed down and continues to criticize state health officials and legislators for not taking her concerns about public health seriously enough. Under the glare of state and national publicity,* the state now supports research on the problem and since 1997 has had a moratorium on construction new hog farms (due to expire in July 2001).

Research by other scientists has confirmed the link between *Pfiesteria* outbreaks and nutrient overloading of rivers. Since 1997, a number of federal and state environmental, health, and agricultural agencies have set up a coordinated research effort to learn more about what triggers outbreaks of the organism and how they affect humans and other organisms.

*For a popularized description of her research and political battle to alert the public and elected officials to the dangers posed by this microbe, see Rodney Barker's *And the Waters Turned to Blood: The Ultimate Biological Threat* (New York: Simon & Schuster, 1997).

many streams in Canada, Japan, and most western European countries. A spectacular cleanup has occurred in Great Britain. In the 1950s the Thames River was little more than a flowing anaerobic sewer. However, after more than 40 years of effort and hundreds of millions of dollars spent by British taxpayers and private industry, the Thames has made a remarkable recovery. Commercial fishing is thriving, and many species of waterfowl and wading birds have returned to their former feeding grounds.

What Is the Bad News About Stream Pollution? Despite progress in improving stream quality in most developed countries, large fish kills and drinking water contamination still occur. Most of these disasters are caused by **(1)** accidental or deliberate releases of toxic inorganic and organic chemicals by industries or mines (Case Study, p. 328), **(2)** malfunctioning sewage treatment plants, and **(3)** nonpoint runoff of pesticides and nutrients (eroded soil, fertilizer, and animal waste) from cropland or animal feedlots (Individuals Matter, above).

Available data indicate that stream pollution from discharges of sewage and industrial wastes is a serious and growing problem in most developing countries, where waste treatment is practically nonexistent. Numerous streams in the former Soviet Union and in eastern European countries are severely polluted. Currently, more than two-thirds of India's water resources are polluted with industrial wastes and sewage. Of the 78 streams monitored in China, 54 are seriously polluted with untreated sewage and industrial wastes. About 20% of China's rivers are too polluted to use for irrigation, and 80% of them are so degraded they no longer support fish. In Latin America and Africa, most streams passing through urban or industrial areas are severely polluted.

What Are the Pollution Problems of Lakes? In lakes, reservoirs, and ponds, dilution often is less effective than in streams because:

- Lakes and reservoirs often contain stratified layers (Figure 7-14, p. 165) that undergo little vertical mixing.
- They have little flow. For example, the flushing and changing of water in lakes and large artificial reservoirs can take from 1 to 100 years, compared with several days to several weeks for streams.
- Ponds contain small volumes of water.

As a result, lakes, reservoirs, and ponds are more vulnerable than streams to contamination by plant nutrients, oil, pesticides, and toxic substances such as lead, mercury, and selenium. These contaminants can destroy both bottom life and fish and birds that feed on contaminated aquatic organisms.

Many toxic chemicals and acids (Figure 17-9, p. 428) also enter lakes and reservoirs from the atmosphere. Concentrations of some chemicals, such as DDT (Figure 16-4, p. 399), PCBs (Figure 19-4), some radioactive isotopes, and some mercury compounds can be biologically magnified as they pass through food webs in lakes.

Lakes receive inputs of nutrients and silt from the surrounding land basin as a result of natural erosion and runoff. This natural nutrient enrichment of lakes is called **eutrophication**. Over time, some lakes become more eutrophic (Figure 7-15, bottom, p. 166), but others do not because of differences in the surrounding drainage basin.

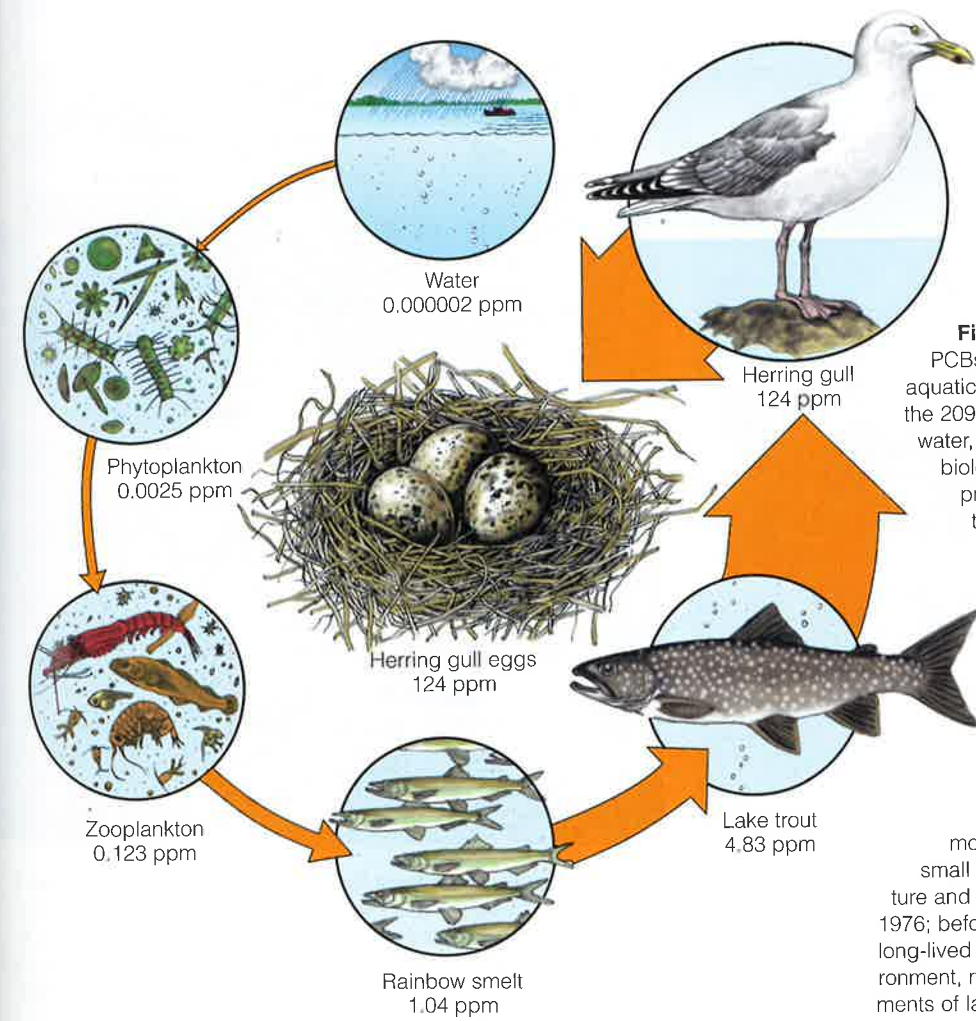


Figure 19-4 Biological magnification of PCBs (polychlorinated biphenyls) in an aquatic food chain in the Great Lakes. Most of the 209 different PCBs are **(1)** insoluble in water, **(2)** soluble in fats, and **(3)** resistant to biological and chemical degradation—properties that result in their accumulation in the tissues of organisms and their biological amplification in food chains and webs. Although the long-term health effects on people exposed to low levels of PCBs are unknown, high doses of PCBs in laboratory animals produce **(1)** liver and kidney damage, **(2)** gastric disorders, **(3)** birth defects, **(4)** skin lesions, **(5)** hormonal changes, **(6)** smaller penis size, and **(7)** tumors. Boys in Taiwan exposed to PCBs while in their mothers' wombs developed abnormally small penises. In the United States, manufacture and use of PCBs have been banned since 1976; before then, millions of metric tons of these long-lived chemicals were released into the environment, many of them still found in bottom sediments of lakes, streams, and oceans.

Near urban or agricultural areas, human activities can greatly accelerate the input of plant nutrients to a lake, which results in a process known as **cultural eutrophication**. Such a change is caused mostly by nitrate- and phosphate-containing effluents from **(1)** sewage treatment plants, **(2)** runoff of fertilizers and animal wastes, and **(3)** accelerated erosion of nutrient-rich topsoil (Figure 19-5).

This excessive input of plant nutrients does not poison lakes and ponds, and such lakes are not by any means "dead," as is sometimes reported. Instead, the high nutrient input overnourishes the plant life in such lakes and causes populations of algae and cyanobacteria to explode (Figure 19-6, right). This disrupts **(1)** their nitrogen (Figure 4-30, p. 94) and phosphorus (Figure 4-32, p. 96) cycles and **(2)** the distribution and types of organisms found in such bodies of water.

During hot weather or drought, this nutrient overload produces dense growths of organisms such as algae, cyanobacteria (Figure 19-6, right), water hyacinths, and duckweed. Dissolved oxygen (in both the surface layer of water near the shore and in the bottom layer) is depleted when large masses of algae die, fall to the bottom, and are decomposed by aerobic bacteria. This oxygen depletion can kill fish and other aerobic aquatic animals. If excess nutrients continue to flow into a lake, anaerobic bacteria take over and produce gaseous decomposition products such as smelly, highly toxic hydrogen sulfide and flammable methane.

About one-third of the 100,000 medium to large lakes and about 85% of the large lakes near major population centers in the United States suffer from some degree of cultural eutrophication. One-fourth of China's lakes are classified as eutrophic.

Ways to *prevent* or reduce cultural eutrophication include **(1)** advanced waste treatment (Section 19-5), **(2)** bans or limits on phosphates in household detergents and other cleaning agents, and **(3)** soil conservation and land-use control to reduce nutrient runoff.

Major *cleanup methods* are **(1)** removing excess weeds, **(2)** controlling undesirable plant growth with herbicides and algicides, and **(3)** pumping air through lakes and reservoirs to avoid oxygen depletion (an expensive and energy-intensive method). As usual, pollution prevention is more effective and usually cheaper in the long run than cleanup.

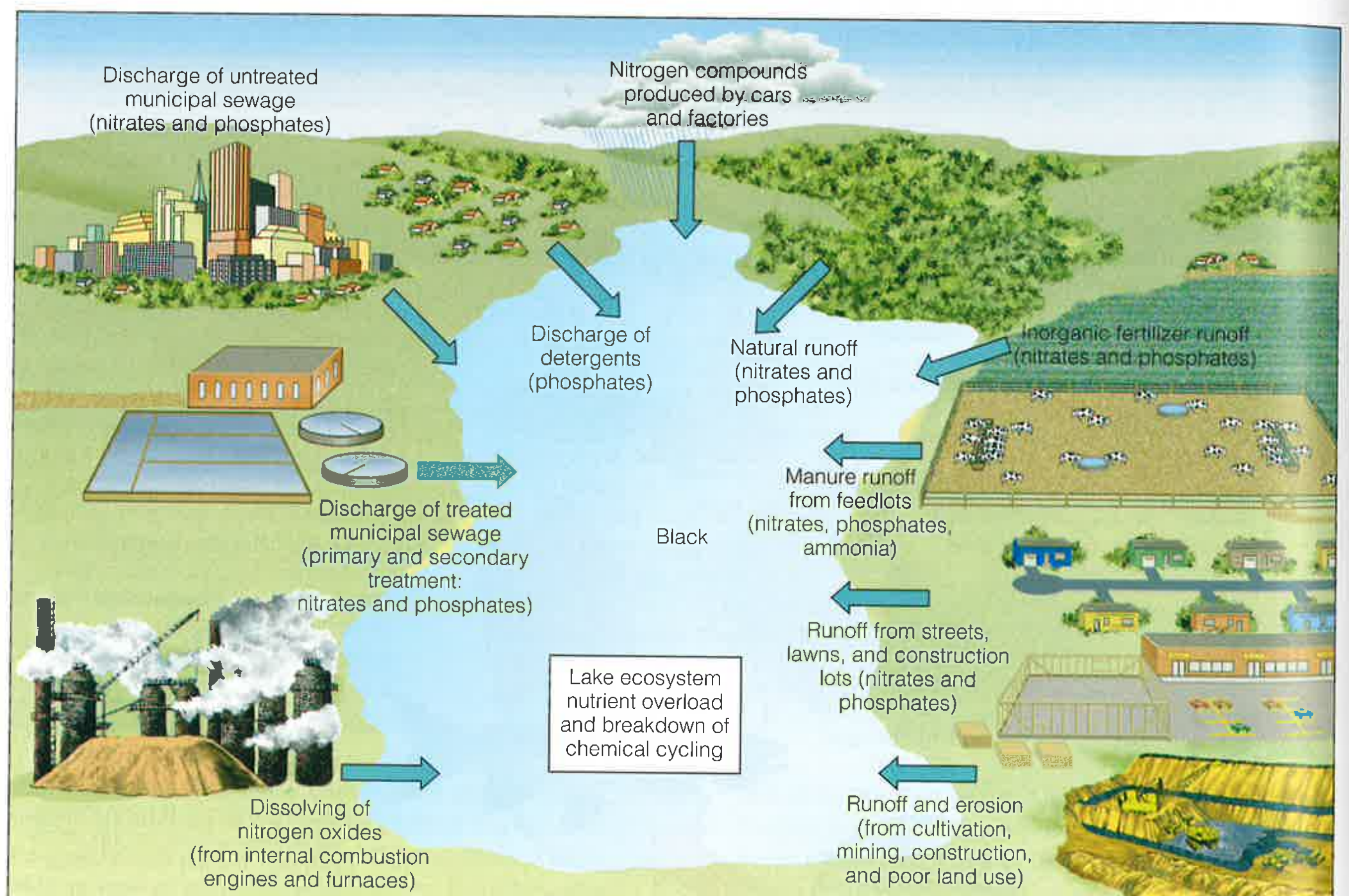


Figure 19-5 Principal sources of nutrient overload causing *cultural eutrophication* in lakes. The amount of nutrients from each source varies according to the types and amounts of human activities occurring in each airshed and watershed. Levels of dissolved oxygen (Figure 19-2) drop when enlarged populations of algae and plants (stimulated by increased nutrient input) die and are decomposed by aerobic bacteria. Lowered oxygen levels can kill fish and other aquatic life and reduce the aesthetic and recreational value of the lake.

Case Study: Chemical Pollution in the Great Lakes The five interconnected Great Lakes (Figure 19-7) contain at least 95% of the fresh surface water in the United States and 20% of the world's fresh surface water. The Great Lakes basin is home for about 38 million people—about 30% of the Canadian population and 14% of the U.S. population. Its huge drainage basin receives inputs of water and pollutants from seven states and much of Ontario in Canada (Figure 19-7).

Despite their enormous size, these lakes are vulnerable to pollution from point and nonpoint sources because less than 1% of the water entering the Great Lakes flows out to the St. Lawrence River each year. In addition to land runoff, these lakes receive large quantities of acids, pesticides, and other toxic chemicals by deposition from the atmosphere (often blown in from hundreds or thousands of kilometers away).

By the 1960s, many areas of the Great Lakes were suffering from severe cultural eutrophication, huge fish kills, and contamination from bacteria and a variety of toxic industrial wastes. The impact on Lake Erie was particularly intense because it is the shallowest of the Great Lakes and it has the highest concentrations of people and industrial activity along its shores. Many bathing beaches had to be closed, and by 1970 the lake had lost nearly all its native fish (Figure 19-8, left).

Here is some *good news*. Since 1972, a $20-billion Great Lakes pollution control program has been carried out jointly by Canada and the United States. This joint program has **(1)** significantly decreased levels of phosphates, coliform bacteria, and many toxic industrial chemicals, **(2)** decreased algae blooms, **(3)** increased dissolved oxygen levels and sport and commercial fishing catches (Figure 19-8, right), and **(4)** allowed most swimming beaches to reopen.

These improvements occurred mainly because of **(1)** new or upgraded sewage treatment plants, **(2)** better treatment of industrial wastes, and **(3)** banning of phosphate detergents, household cleaners, and water conditioners.

Here is some *bad news*:

- Less than 3% of the lakes' shoreline is clean enough for swimming or for supplying drinking water.
- Nonpoint land runoff of pesticides and fertilizers from urban sprawl has surpassed industrial pollution as the greatest threat to the lakes.
- Forty-three toxic hot spots (Figure 19-7) are still heavily polluted.
- Atmospheric deposition of pesticides, mercury from coal-burning plants, and other toxic chemicals from as far as Mexico and Russia account for an estimated 50% of the input of toxic compounds.

Figure 19-6 The effect of nutrient enrichment on a lake. Crater Lake in Oregon (left) is an example an oligotrophic lake (Figure 7-15, top, p. 166) that is low in nutrients. Because of a low density of plankton, its water is quite clear. The lake on the right, found in western New York, is a eutrophic lake (Figure 7-15, bottom, p. 166). Because of an excess of plant nutrients, its surface is covered with mats of algae and cyanobacteria. (Left, Jack Carey; right, W. A. Bannazewski, Visuals Unlimited)

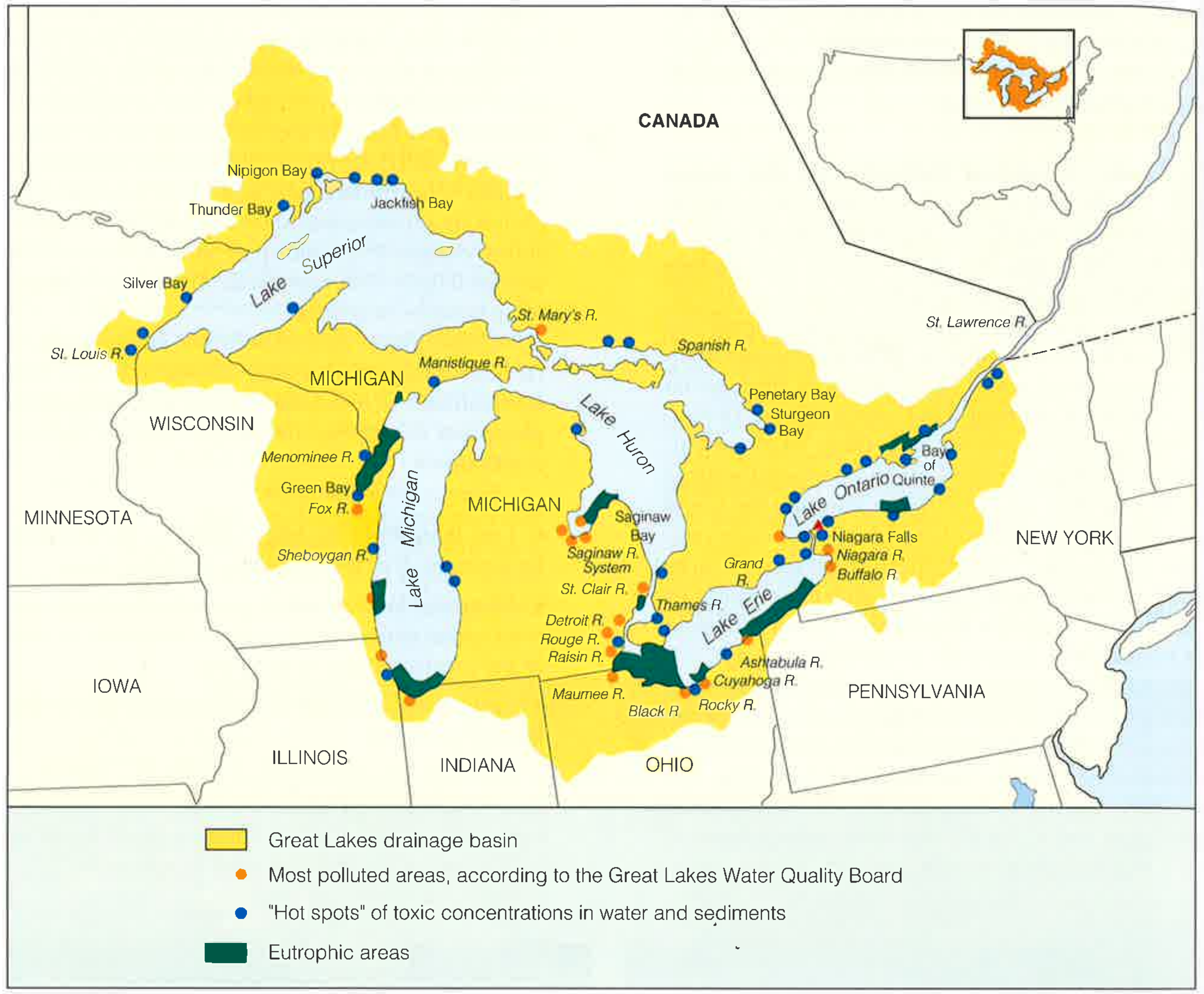


Figure 19-7 The Great Lakes basin and the locations of some of its water quality problems. The Great Lakes region is dotted with several hundred abandoned toxic waste sites that are listed by the EPA as Superfund sites to receive cleanup priority (p. 543). (Data from Environmental Protection Agency)

- Toxic chemicals such as PCBs have **(1)** built up in food chains and webs (Figure 19-4), **(2)** contaminated many types of sport fish, and **(3)** depleted populations of birds, river otters, and other animals feeding on contaminated fish.
- A survey by Wisconsin biologists revealed that one fish in four taken from the Great Lakes is unsafe for human consumption.

In 1991, the U.S. government passed a law requiring accelerated cleanup of the lakes, especially 43 toxic hot spots, and an immediate reduction in air pollutant emissions in the region. However, a lack of federal and state funds may delay meeting these goals.

Some environmentalists call for a ban on **(1)** the use of chlorine as a bleach in the pulp and paper industry around the Great Lakes, **(2)** all new incinerators in the area, and **(3)** discharge into the lakes of 70 toxic chemicals that threaten human health and wildlife. Officials of these industries strongly oppose such bans.

Connections: How Might Projected Climate Change Affect Water Pollution? Global warming (Section 18-4, p. 458) can affect water quality by putting more water vapor into the atmosphere and altering existing patterns of precipitation. As a result, some areas will get much more precipitation and others will experience more prolonged drought.

A moisture-laden atmosphere generates more intense downpours, which can flush more harmful chemicals, plant nutrients, and microorganisms into waterways. Massive flooding, whether caused by normal weather patterns or human impacts on climate, often spreads disease-carrying pathogens (Table 19-2) by **(1)** contaminating water treatment facilities and wells and **(2)** causing the overflow of animal waste lagoons and combined sewer lines (Case Study, p. 486). Warmer water temperatures can also increase the rate at which harmful microorganisms such as *Salmonella* grow.

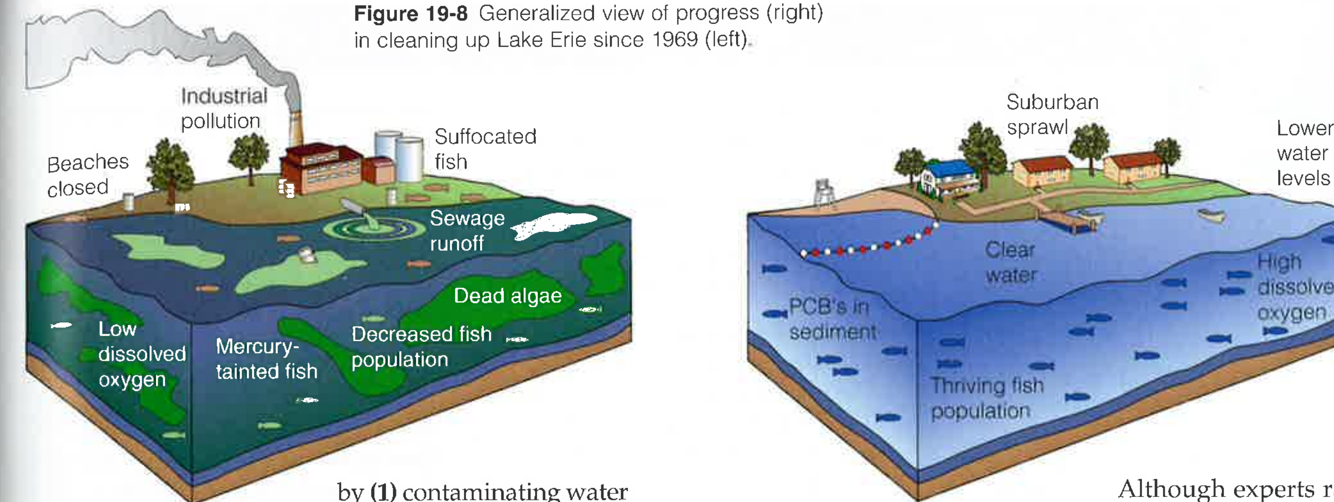


Figure 19-8 Generalized view of progress (right) in cleaning up Lake Erie since 1969 (left).

Waterborne infectious diseases can also increase in countries experiencing prolonged drought as a result of climate change. In drought conditions, disease can spread more rapidly because people lack enough water to stay clean.

19-3 GROUNDWATER POLLUTION AND ITS PREVENTION

Why Is Groundwater Pollution Such a Serious Problem? According to many scientists, a serious threat to human health is the out-of-sight pollution of groundwater, a prime source of water for drinking and irrigation. Groundwater supplies about 75% of the drinking water in Europe, 51% in the United States, 32% in Asia, and 29% in Latin America. In selected parts of the world, essentially all drinking and irrigation water is pumped up from aquifers.

Studies indicate that groundwater pollution comes from numerous sources as we dump more of our wastes into **(1)** storage lagoons, **(2)** septic tanks, **(3)** landfills, **(4)** hazardous waste dumps, and **(5)** deep injection wells and store gasoline, oil, solvents, and hazardous wastes in metal underground tanks that after 20–40 years can corrode and leak (Figure 19-9). Groundwater is also contaminated by people who dump or spill gasoline, oil, and paint thinners and other organic solvents onto the ground.

Groundwater in aquifers is easy to deplete (Case Study, p. 309) and pollute because much of it is renewed very slowly. For example, the average recycling time for groundwater is about 1,400 years, compared to only 20 days for river water.

Although experts rate groundwater pollution as a low-risk ecological problem, they consider pollutants in drinking water (much of it from groundwater) a high-risk health problem (Figure 16-13, left, p. 411). Human health risks come mostly from groundwater contaminated with **(1)** petrochemicals (such as gasoline and oil), **(2)** organic solvents (such as trichloroethylene, or TCE), **(3)** pesticides, **(4)** arsenic (As), **(5)** lead (Pb), and **(6)** fluoride (F^-; Table 19-1).

When groundwater becomes contaminated, it cannot cleanse itself of *degradable wastes* as flowing surface water does (Figure 19-3) because **(1)** it flows so slowly (usually less than 0.3 meters or 1 foot per day) that contaminants are not diluted and dispersed effectively, **(2)** it has much smaller populations of decomposing bacteria, and **(3)** its cold temperature slows down the chemical reactions that decompose wastes. This means that it can take hundreds to thousands of years for contaminated groundwater to cleanse itself of *degradable* wastes, and on a human time scale *nondegradable wastes* (such as toxic lead, arsenic, and fluoride) are there permanently.

What Is the Extent of Groundwater Pollution? The answer is that *we do not know* because few countries go to the great expense of locating, tracking, and testing aquifers. However, studies that have been made by scientists in scattered parts of the world are alarming. Here are a few of the findings:

- Up to 25% of usable groundwater in the United States is contaminated (and in some areas as much as 75%). In New Jersey, for example, every major aquifer is contaminated.
- The EPA has documented groundwater contamination by 74 pesticides in 38 states, mostly in farming regions. In California, pesticides contaminate the drinking water of more than 1 million people. Contamination of groundwater by pesticides has also been found in farming regions of western Europe, south Asia, and Latin America.

Hurricanes, Hog Farms, and Water Pollution in Eastern North Carolina

CASE STUDY

With 10 million animals statewide, North Carolina is the nation's second largest hog producer, after Iowa. Ninety-percent of the state's 2,400 hog farms in this $1.9-billion-per-year business are located in a portion of eastern North Carolina. The area is also a large producer of poultry.

In 1999, three hurricanes dropped more than 0.9 meter (3 feet) of rain in less than 2 months on eastern North Carolina, with the largest coming from Hurricane Floyd in September. The resulting massive flooding:

- Knocked out electricity in at least 24 municipal sewage treatment plants, causing large spills of raw sewage into coastal rivers.
- Covered more than 50 hog and poultry waste lagoons, collapsed five lagoons, and released large amounts of animal waste into nearby streams, rivers, residential areas, and water supplies—a potential danger that biologist JoAnn M. Burkholder (Individuals Matter, p. 480) had warned about in 1991.
- Required hog and poultry farmers to pump large volumes of diluted animal wastes onto nearby fields from hundreds of other lagoons to keep them from overflowing or collapsing.
- Caused structural damage to a number of the area's 2,000 other animal waste lagoons that could make them vulnerable to future flooding.
- Polluted houses and wells, broke water mains, and threatened water supplies with bacteria, viruses, and parasites. After Floyd, a health crisis was largely averted because National Guard helicopters and trucks delivered clean water to several counties.

The stormwater **(1)** became mixed with raw human and animal sewage, junkyard waste, leaking underground gasoline tanks and oil drums, and pesticide-laced sediments from farm fields and **(2)** poured down rivers into Pamlico Sound, the nation's second largest estuary. Water and wastes flowing into this estuary remained there for about a year because it only has three small outlets to the Atlantic Ocean.

Critical Thinking

What three things could the government of North Carolina do to help reduce water pollution and other harmful effects from flooding caused by future hurricanes and large storms?

- According to the EPA and the U.S. Geological Survey, about 45% of *municipal* groundwater supplies in the United States are contaminated with one or more organic chemicals.
- A 2000 U.S. Geological Survey study found that about 42 million Americans use groundwater that is subject to contamination by volatile organic compounds (VOCs; Figure 19-10)
- An EPA survey found that **(1)** one-third of 26,000 industrial waste ponds and lagoons in the United States have no liners to prevent toxic liquid wastes from seeping into aquifers, and **(2)** one-third of these sites are within 1.6 kilometers (1 mile) of a drinking water well.
- The EPA estimates that at least 1 million underground tanks storing gasoline, diesel fuel, home heating oil, and toxic solvents are leaking their contents into groundwater in the United States. A slow leak of just 4 liters (1 gallon) of gasoline per day can contaminate the water supply for 50,000 people. During this century, scientists expect many of the millions of such tanks installed around the world in recent decades to corrode, leak, contaminate groundwater, and become a major global health problem.
- Determining the extent of a leak from an underground tank can cost $25,000–250,000, and cleanup costs range from $10,000 to more than $250,000. If the chemical reaches an aquifer, effective cleanup is rarely possible. Replacing a leaking tank adds an additional $10,000–60,000. In California's Silicon Valley, where electronics industries use underground tanks to store a variety of waste solvents, local authorities found leaks from 85% of the tanks they inspected.
- About 60% of the liquid hazardous waste in the United States is disposed of by injections into deep underground wells (Figure 19-9). Although these wastes are injected below the deepest sources of drinking water, some of the injection pipes can leak, and some of the wastes have entered aquifers used for drinking water in parts of Texas, Florida, Oklahoma, and Ohio.
- Groundwater contamination by toxic *arsenic (As)* can occur when tubewells are drilled in areas where the soils are naturally rich in arsenic (such as India's state of West Bengal and parts of Bangladesh, where 35–77 million people are drinking water with arsenic levels 5–100 times the World Health Organization limit).

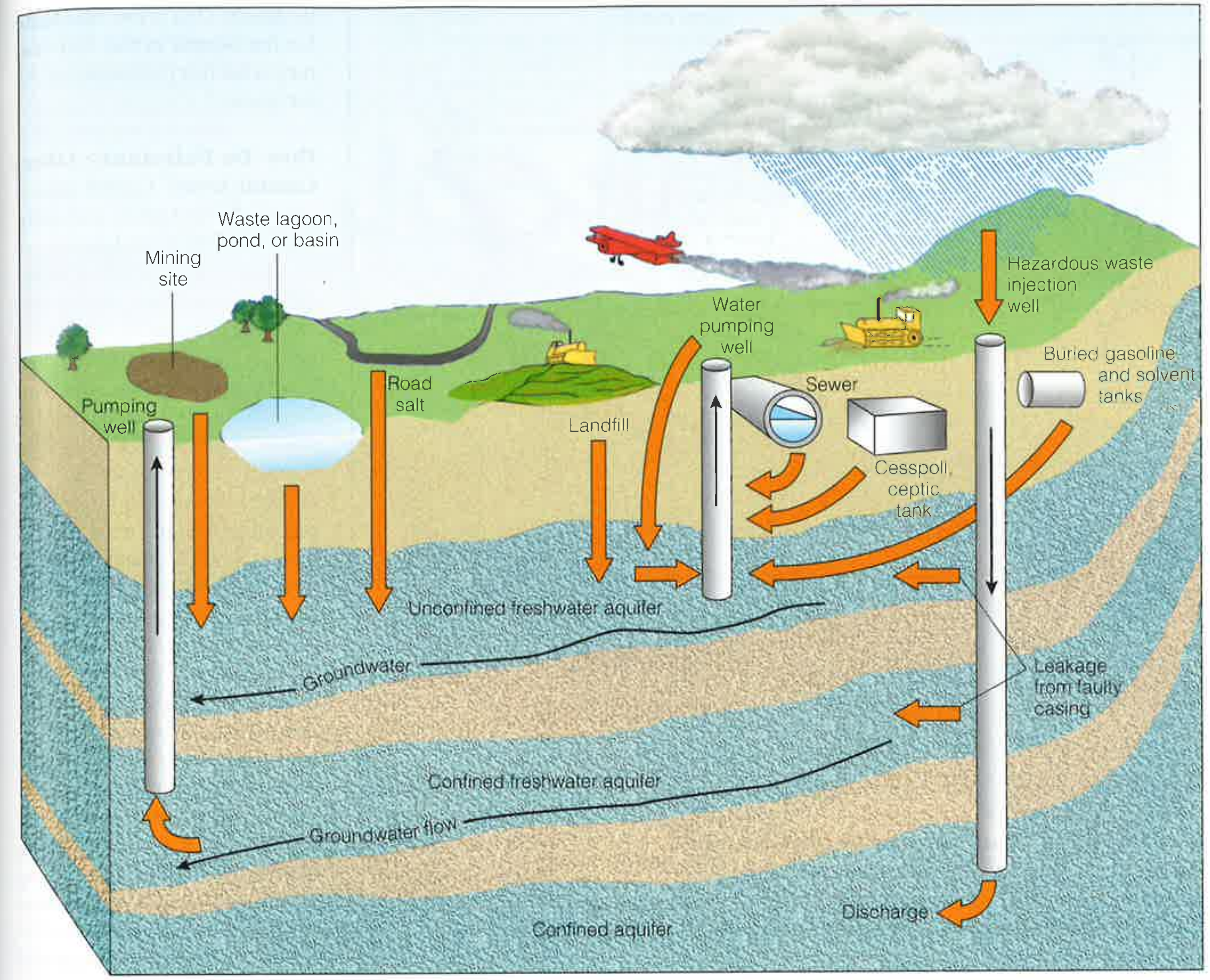


Figure 19-9 Principal sources of groundwater contamination in the United States.

- According to the World Health Organization, an estimated 70 million people in northern China and 30 million in northwestern India drink groundwater contaminated with high levels of naturally occurring *fluoride* (F^-). This can cause crippling backbone and neck damage and a variety of dental problems.
- In coastal areas, excessive pumping of water from aquifers can lead to contamination of drinking water by saltwater intrusion (Figure 13-17, p. 308).

Solutions: How Can We Protect Groundwater? Contaminated aquifers are almost impossible to clean because of their **(1)** enormous volume, **(2)** inaccessibility, and **(3)** slow movement. Pumping polluted groundwater to the surface, cleaning it up, and returning it to the aquifer is extremely expensive. Moreover, recent attempts to pump and treat contaminated aquifers indicate that it may take 50–1,000 years of continuous pumping before all the contamination is forced to the surface and drinking water quality is achieved. Thus, *preventing contamination is considered the only effective way to protect groundwater resources.* Ways to do this include:

- *Monitoring aquifers near landfills and underground tanks.*
- *Requiring leak detection systems for underground tanks used to store hazardous liquids.*
- *Banning or more strictly regulating disposal of hazardous wastes in deep injection wells and landfills.*
- *Storing hazardous liquids above ground in tanks with systems that detect and collect leaking liquids.*

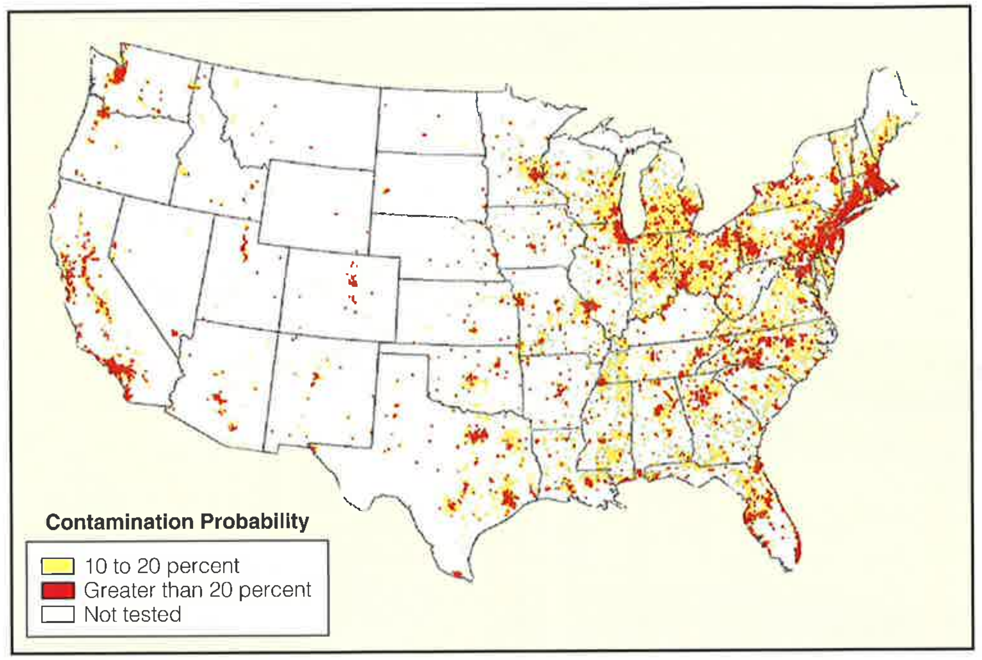


Figure 19-10 Probability of drinking water contamination by volatile organic compounds (VOCs) in the 48 contiguous states. John Zorgoski, who headed the study, urges people who live in areas with red or yellow dots to have their well and municipal water tested for VOCs. (Data from the U.S. Geological Survey)

19-4 OCEAN POLLUTION

How Much Pollution Can the Oceans Tolerate? The oceans are the ultimate sink for much of the waste matter we produce, as summarized in the African proverb, "Water may flow in a thousand channels, but it all returns to the sea."

Oceans can dilute, disperse, and degrade large amounts of raw sewage, sewage sludge, oil, and some types of degradable industrial waste, especially in deep-water areas. Some forms of marine life have also proved to be more resilient than originally expected. This has led some analysts to suggest that it is safer to dump sewage sludge and most other hazardous wastes into the deep ocean than to bury them on land or burn them in incinerators.

Other scientists disagree, pointing out that we know less about the deep ocean than we do about outer space. They add that dumping waste in the ocean would delay urgently needed pollution prevention and promote further degradation of this vital part of the earth's life-support system.

There is increasing agreement that we must greatly increase funding to help us understand more about how the oceans work and how to help sustain their natural processes and biodiversity (Chapter 24). According to oceanographer Sylvia Earle, "We've made the investment to venture into the skies, and it has paid off mightily. We've neglected the oceans, and it has cost us dearly. This is the time to do for the oceans in the 21st century what our predecessors did for space."

How Do Pollutants Affect Coastal Areas? Coastal areas—especially wetlands and estuaries, coral reefs, and mangrove swamps—bear the brunt of our enormous inputs of wastes into the ocean (Figure 19-11). This is not surprising because **(1)** about 40% the world's population lives on or within 100 kilometers (160 miles) of the coast, **(2)** 14 of the world's 15 largest metropolitan areas, each with 10 million people or more, are near coastal waters, and **(3)** coastal populations are growing more rapidly than the global population.

In most coastal developing countries (and in some coastal developed countries), municipal sewage and industrial wastes are dumped into the sea without treatment. The most polluted seas lie off the densely populated coasts of Bangladesh, India, Pakistan, Indonesia, Malaysia, Thailand, and the Philippines. About 85% of the sewage from large cities along the Mediterranean Sea, which has a coastal population of 200 million people during tourist season, is discharged into the sea untreated. This causes widespread beach pollution and shellfish contamination.

Most U.S. harbors and bays are badly polluted by municipal sewage, industrial wastes, and oil. Scuba divers talk of swimming through clouds of half-dissolved feces and of bay and harbor bottoms covered with toxic sediment known as black mayonnaise. They see lobsters and crabs covered with mysterious burn holes and fish with cancerous sores and rotting fins. Each year at least one-third of the area of U.S. coastal waters around the lower 48 states is closed to shellfish harvesting because of pollution and habitat disruption.

New studies show that vast colonies of human viruses from raw sewage, effluents from sewage treatment plants (which do not remove viruses), and leaking septic tanks migrate into coastal waters. One study found that about one-fourth of the people using coastal beaches develop ear infections, sore throats and eyes, respiratory disease, or gastrointestinal disease.

Runoff of sewage and agricultural wastes into coastal waters and acid deposition from the atmosphere (Figure 17-9, p. 428) introduce large quantities of nitrate

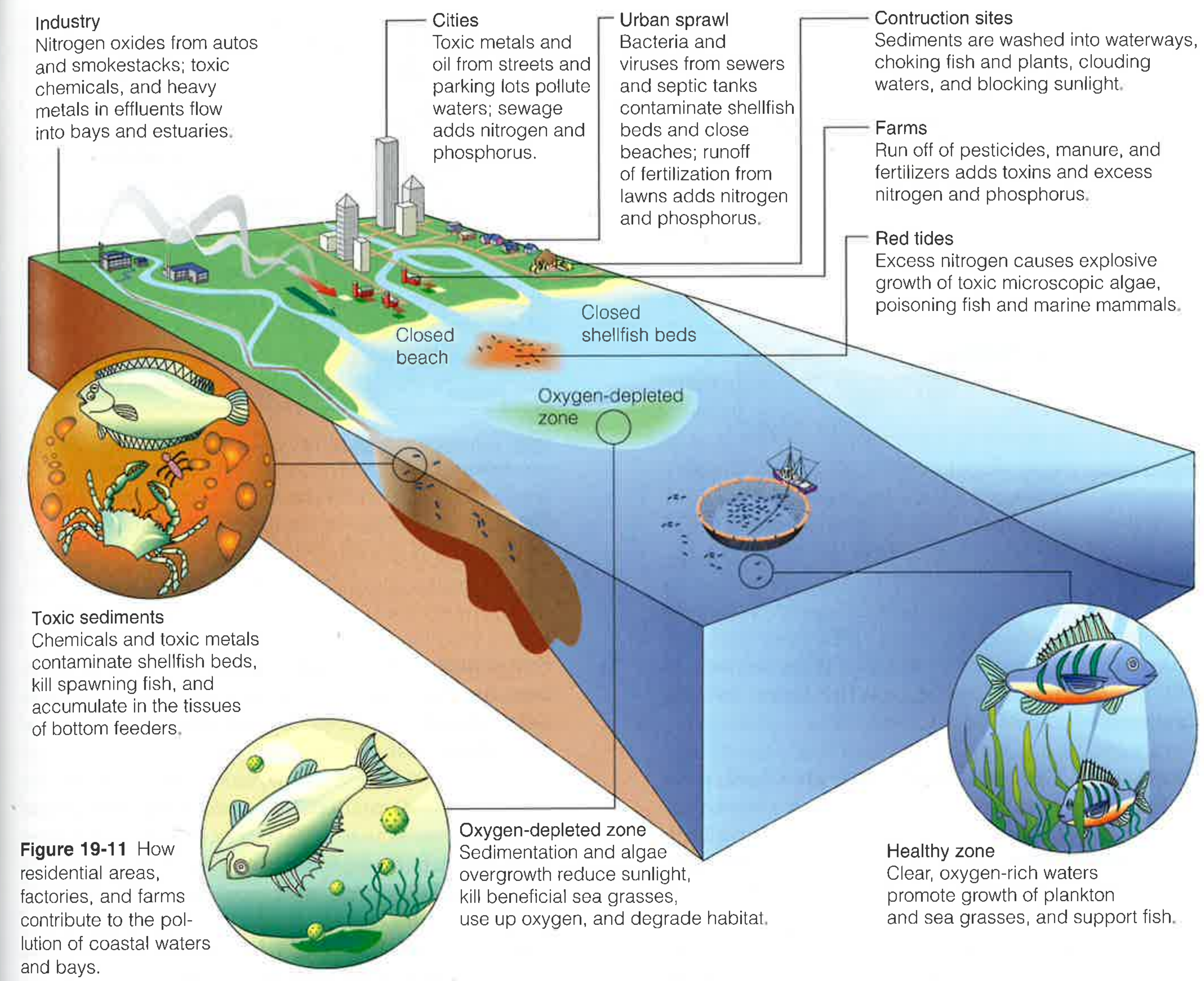


Figure 19-11 How residential areas, factories, and farms contribute to the pollution of coastal waters and bays.

(NO_3^-) and phosphate (PO^{3-}) plant nutrients, which can cause explosive growth of harmful algae.

These algal blooms—called red, brown, or green tides, depending on their color—can **(1)** release waterborne and airborne toxins that damage fisheries, **(2)** kill some fish-eating birds, **(3)** reduce tourism, and **(4)** poison seafood. When the algae die and decompose, coastal waters are depleted of oxygen, and a variety of marine species die.

According to a 2000 report by the U.S. National Academy of Sciences, fish and other marine life are being killed in more than a third of the nation's coastal areas from algae blooms caused by runoff of excess plant nutrients. Each year some 61 large *oxygen-depleted zones* (sometimes inaccurately called a dead zones) form in the world's coastal waters and in landlocked seas such as the Baltic and Black because of excessive fertilizer inputs. In these zones, much of the aquatic life dies or moves elsewhere.

The biggest such zone in U.S. waters and the third largest in the world forms every summer in a narrow stretch of the Gulf of Mexico (Figure 19-12). For half the year, this zone in the Gulf of Mexico is rich with shrimp, fish, and many other forms of aquatic life. However, the spring snowmelt and rains flush nitrogen and phosphorus fertilizers from farms and cities throughout the Mississippi River's giant watershed, which covers more than 40% of the continental United States from Montana to western New York (Figure 19-12). As a result, this zone becomes overfertilized, depleted of oxygen, and devoid of fish and many other creatures for about 6 months a year. By summer, the oxygen-depleted zone covers about 20,700 square kilometers (8,000 square miles).

In the Baltic Sea, excessive cultural eutrophication has killed almost all bottom-dwelling animal life over an area of about 109,000 square kilometers (42,000 square miles)—about the size of Guatemala or Tennessee. In 1998, a deadly red tide appeared on the

Figure 19-12 A large zone of oxygen-depleted water forms for half of the year in the Gulf of Mexico as a result of oxygen-depleting algal blooms. It is created by huge inputs of nitrate (NO_3^-) and phosphate (PO_4^{3-}) plant nutrients from the massive Mississippi River Basin.

China coast, where none has been recorded before. Within a few hours, it wiped out fish farms, leaving thousands of tons of rotting fish.

Case Study: The Chesapeake Bay The Chesapeake Bay, the largest estuary in the United States, is in trouble because of human activities. Between 1940 and 2000, the number of people living in the Chesapeake Bay area grew from 3.7 million to 17 million, and within a few years its population may reach 18 million.

The estuary receives wastes from point and nonpoint sources scattered throughout a huge drainage basin that includes 9 large rivers and 141 smaller streams and creeks in parts of six states (Figure 19-13). The bay has become a huge pollution sink because **(1)** it is quite shallow and **(2)** only 1% of the waste entering it is flushed into the Atlantic Ocean.

Phosphate and nitrate levels have risen sharply in many parts of the bay, causing algae blooms and oxygen depletion (Figure 19-13). Studies have shown that point sources, primarily sewage treatment plants, contribute about 60% by weight of the phosphates. Nonpoint sources—mostly runoff from urban, suburban, and agricultural land and deposition from the atmosphere—are the origins of about 60% by weight of the nitrates.

Air pollutants account for nearly 40% of the nitrogen, 90% of the mercury (mostly from older coal-burning power plants), and 95% of the lead entering the estuary. Large quantities of pesticides run off cropland and urban lawns, and industries discharge large amounts of toxic wastes, often in violation of their discharge permits. Commercial harvests of oysters (Solutions, p. 492), crabs, and several important fish have fallen sharply since 1960 because of a combination of overfishing, pollution, and disease.

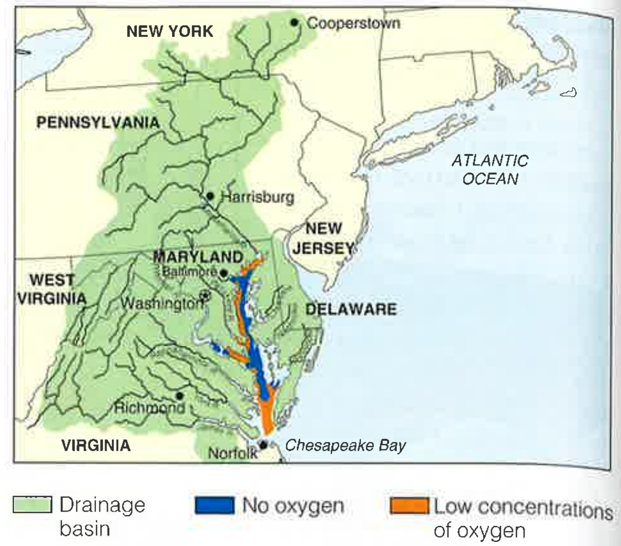


Figure 19-13 Chesapeake Bay, the largest estuary in the United States, is severely degraded as a result of water pollution from point and nonpoint sources in six states and from deposition of air pollutants.

In the 1980s, the Chesapeake Bay Program, the country's most ambitious attempt at integrated coastal management, was implemented. Results have been impressive. Between 1985 and 1993, phosphorus levels declined 16% and nitrogen levels dropped 7%—a significant achievement given the increasing population in the watershed and the fact that nearly 40% of the nitrogen inputs come from the atmosphere.

Reaching the declared goal of a 40% reduction in nutrient levels and a significant improvement in habitat water quality throughout the bay will be especially difficult because the area's population is expected to grow by 25% between 1995 and 2020. So far, however, the Chesapeake Bay Program shows what can be done when diverse interested parties work together to achieve goals that benefit both wildlife and people.

What Pollutants Do We Dump into the Ocean? Industrial waste dumping off U.S. coasts has stopped, although it still occurs in a number of other developed countries and some developing countries. However, barges and ships still legally dump large quantities of **dredge spoils** (materials, often laden with toxic metals, scraped from the bottoms of harbors and rivers to maintain shipping channels) at 110 sites off the Atlantic, Pacific, and Gulf coasts.

In addition, many countries dump into the ocean large quantities of sewage **sludge**: a gooey mixture of toxic chemicals, infectious agents, and settled solids removed from wastewater at sewage treatment plants. Since 1992, this practice has been banned in the United States.

Fifty countries with at least 80% of the world's merchant fleet have agreed not to dump sewage and garbage at sea, but this agreement is difficult to enforce and often is violated. Most ship owners save money by dumping wastes at sea and risk only small fines if they are caught. Each year, as many as 2 million seabirds and more than 100,000 marine mammals (including whales, seals, dolphins, and sea lions) die when they ingest or become entangled in fishing nets, ropes, and other debris dumped into the sea and discarded on beaches.

Under the London Dumping Convention of 1972, 100 countries agreed not to dump highly toxic pollutants and high-level radioactive wastes in the open sea beyond the boundaries of their national jurisdictions. Since 1983, these same nations have observed a moratorium on the dumping of low-level radioactive wastes at sea, which in 1994 became a permanent ban. However, France, Great Britain, Russia, China, and Belgium may legally exempt themselves from this ban. In 1992, it was learned that for decades the former Soviet Union had been dumping large quantities of high- and low-level radioactive wastes into the Arctic Ocean and its tributaries.

What Are the Effects of Oil on Ocean Ecosystems? *Crude petroleum* (oil as it comes out of the ground) and *refined petroleum* (fuel oil, gasoline, and other processed petroleum products, Figure 14-16, p. 337) are accidentally or deliberately released into the environment from a number of sources.

Tanker accidents (Case Study, p. 336) and blowouts at offshore drilling rigs (when oil escapes under high pressure from a borehole in the ocean floor) get most of the publicity. However, more oil is released **(1)** during normal operation of offshore wells, **(2)** from washing tankers and releasing the oily water, and **(3)** from pipeline and storage tank leaks.

Natural oil seeps also release large amounts of oil into the ocean at some sites, but most ocean oil pollution comes from activities on land. Almost half (some experts estimate 90%) of the oil reaching the oceans is waste oil dumped, spilled, or leaked onto the land or into sewers by cities, industries, and individuals changing their own motor oil. Worldwide, about 10% of the oil that reaches the ocean comes from the atmosphere, mostly from smoke emitted by oil fires.

The effects of oil on ocean ecosystems depend on a number of factors: **(1)** type of oil (crude or refined), **(2)** amount released, **(3)** distance of release from shore, **(4)** time of year, **(5)** weather conditions, **(6)** average water temperature, and **(7)** ocean currents.

Volatile organic hydrocarbons in oil immediately kill a number of aquatic organisms, especially in their vulnerable larval forms. Some other chemicals form tarlike globs that float on the surface and coats the feathers of birds (especially diving birds) and the fur of marine mammals. This destroys their natural insulation and buoyancy, causing many of them to drown or die of exposure from loss of body heat. Heavy oil components that sink to the ocean floor or wash into estuaries can smother bottom-dwelling organisms such as crabs, oysters, mussels, and clams or make them unfit for human consumption. Some oil spills have killed reef corals.

Research shows that most (but not all) forms of marine life recover from exposure to large amounts of *crude oil* within 3 years. However, recovery from exposure to *refined oil*, especially in estuaries, can take 10 years or longer. The effects of spills in cold waters and in shallow enclosed gulfs and bays generally last longer (Case Study, p. 336).

Oil slicks that wash onto beaches can have a serious economic impact on coastal residents, who lose income from fishing and tourist activities. Oil-polluted beaches washed by strong waves or currents become clean after about a year, but beaches in sheltered areas remain contaminated for several years. Estuaries and salt marshes suffer the most and longest-lasting damage. Despite their localized harmful effects, experts rate oil spills as a low-risk ecological problem (Figure 16-13, left, p. 411).

How Can Oil Spills Be Cleaned Up? If they are not too large, oils spills can be partially cleaned up by mechanical, chemical, fire, and natural methods. *Mechanical methods* include using **(1)** floating booms to contain the oil spill or keep it from reaching sensitive areas, **(2)** skimmer boats to vacuum up some of the oil into collection barges, and **(3)** absorbent pads or large mesh pillows filled with feathers or hair to soak up oil on beaches or in waters too shallow for skimmer boats.

Chemical methods include the use of **(1)** coagulating agents to cause floating oil to clump together for easier pickup or to sink to the bottom, where it usually does less harm, and **(2)** dispersing agents to break up oil slicks. However, these agents can also damage some types of organisms. Fire can burn off floating oil, but crude oil is hard to ignite, and this approach produces air pollution. In time, the natural action of wind and waves mixes or emulsifies oil with water (like emulsified salad dressing), and bacteria biodegrade some of the oil.

These methods remove only part of the oil, and none work well on a large spill. Scientists estimate that no more than 12–15% of the oil from a major spill can be recovered. This explains why preventing oil pollution is the most effective and in the long run the least

Bring Back the Oysters

SOLUTIONS

A number of scientists and environmentalists are looking for ways to rebuild the Chesapeake Bay's once huge population of the eastern oyster as a way to help clean up the water. Oysters are filter feeders that vacuum up the algae and nutrient-laden suspended silt that cause many of the Chesapeake's problems.

According to aquatic biologist Roger Newell, the bay's once prodigious oyster population served as a natural water purifier by filtering the bay's entire volume of water every 3 or 4 days. However, overharvesting and two parasitic oyster diseases have reduced the oyster population to about 1% of its historic high. As a result, today's oyster population needs about a year to filter the bay's water.

Computer models project that increasing the oyster population to only 10% of its historic high would improve water quality and spur the growth of underwater sea grass. Methods for restoring the bay's oyster population include **(1)** developing disease-resistant oyster stocks, **(2)** seeding protected oyster beds with large, older oysters presumed to have some disease resistance, **(3)** dumping hundreds of millions of oyster shells on dozens of historic reef areas with the goal of resurrecting some of the old oyster breeding reefs, **(4)** trying to find a reef-building substitute to hasten reef reconstruction, **(5)** setting aside 20–25% of the bay's oyster beds as sanctuaries to protect stocks from overfishing, and **(6)** greatly increasing funds for research and implementation of such a program.

Critical Thinking

Should more of the scarce funds for reducing pollution and degradation of the Chesapeake Bay be used to increase the oyster population? Explain.

costly approach, as revealed by the large spill from *Exxon Valdez* oil tanker in 1989 (Case Study, p. 336). However, a 1998 study by a National Aeronautics and Space Agency (NASA) scientist concluded that mesh pillows filled with 640 metric tons (700 tons) of hair could have soaked up the entire *Exxon Valdez* oil spill in a weeks, saving much of the $2 billion Exxon spent to capture only about 12% of the oil spilled.

Solutions: How Can We Protect Coastal Waters? The key to protecting oceans is to reduce the flow of pollution from the land and from streams emptying into the ocean. Such efforts must be integrated with efforts to prevent and control air pollution because an estimated 33% of all pollutants entering the ocean worldwide comes from air emissions from land-based sources.

Analysts have suggested the following measures to prevent and reduce excessive pollution of coastal waters:

Prevention

- *Use separate sewage and storm runoff lines in coastal urban areas.* Otherwise, excessive rainfall causes lines carrying sewage and storm runoff to overflow and release raw sewage into coastal waters.
- *Discourage or ban ocean dumping of sludge and hazardous dredged materials.*
- *Protect sensitive and ecologically valuable coastal areas from development, oil drilling, and oil shipping.*
- *Regulate coastal development.*
- *Require double hulls for all oil tankers.*
- *Recycle used oil.*

Cleanup

- *Improve oil spill cleanup capabilities.*
- *Require at least secondary treatment of coastal sewage, or use wetlands, solar aquatic (p. 476), or other treatment methods.*

19-5 SOLUTIONS: PREVENTING AND REDUCING SURFACE WATER POLLUTION

What Can We Do About Water Pollution from Nonpoint Sources? Ways to help control nonpoint water pollution, most of it from agriculture, include the following:

- Reduce fertilizer runoff into surface waters and leaching into aquifers by using slow-release fertilizer and using none on steeply sloped land.
- Reduce the need for fertilizer by alternating plantings between row crops and soybeans or other nitrogen-fixing plants.
- Plant buffer zones of vegetation between cultivated fields and nearby surface water.
- Reduce pesticide runoff by applying pesticides only when needed and using biological control or integrated pest management (p. 515).
- Control runoff and infiltration of manure from animal feedlots by **(1)** improving manure control, **(2)** planting buffers, and **(3)** not locating feedlots and animal waste on steeply sloped land near surface water and in flood zones.
- Reduce soil erosion and flooding by reforesting critical watersheds.

Under the U.S. Clean Water Act, states are required to protect watersheds from nonpoint water pollution from farms and forests. States are supposed to designate waterways impaired by such pollution and develop a plan to curtail the pollution. However, a 2000 study by the National Wildlife Federation shows that 38 of the 50 states have done little to address nonpoint water pollution under this federal law.

What Can We Do About Water Pollution from Point Sources? The Legal Approach According to Sandra Postel, director of the Global Water Policy Project, most cities in developing countries discharge 80–90% of their untreated sewage directly into rivers, streams, and lakes, which are used for drinking water, bathing, and washing clothes.

In Latin America, less than 2% of urban sewage is treated. In China, only 4.5% of municipal wastewater and 17% of industrial discharge is treated. In India, only about 209 of its 3,100 largest cities have partial waste treatment plants, and only 8 have modern waste treatment plants.

In developed countries, most wastes from point sources are purified to varying degrees. The Federal Water Pollution Control Act of 1972 (renamed the Clean Water Act when it was amended in 1977) and the 1987 Water Quality Act form the basis of U.S. efforts to control pollution of the country's surface waters.

In 1995, the EPA developed a *discharge trading policy* designed to use market forces to reduce water pollution (as has been done with sulfur dioxide for air pollution control, p. 441). The policy would allow a water pollution source, such as an industrial plant or a sewage treatment plant, to sell credits for its excess reductions to another facility that cannot reduce its discharges as cheaply.

Here is some *good news*. The Clean Water Act of 1972 led to the following improvements in U.S. water quality between 1972 and 1998: **(1)** The percentage of U.S. rivers and lakes tested that are fishable and swimmable increased from 36% to 62%, **(2)** the amount of topsoil lost through agricultural runoff was cut by about 1.1 billion metric tons (1 billion tons) annually, **(3)** the proportion of the U.S. population served by sewage treatment plants increased from 32% to 74%, and **(4)** annual wetland losses decreased by 83%.

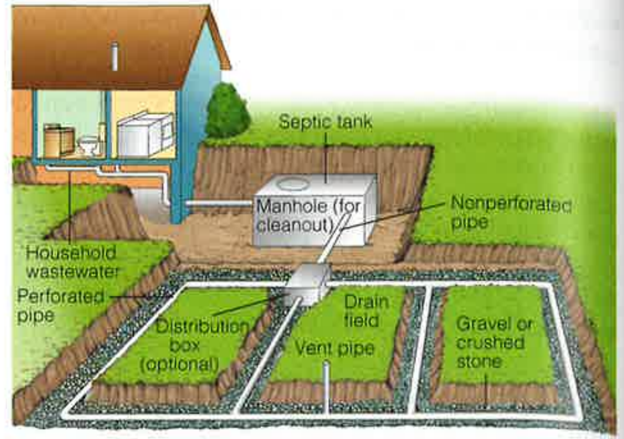
Here is some *bad news*: **(1)** About 44% of lakes, 38% of rivers (up from 26% in 1984), and 32% of estuaries in the United States are still unsafe for fishing, swimming, and other recreational uses, **(2)** of 27,300 surface waters analyzed in 1998, 12–17% were impaired by sediments, excessive nutrients, pathogens, and low oxygen levels, **(3)** hog, poultry, and cattle farm runoff pollutes 70% of U.S. rivers, **(4)** despite aggressive monitoring nearly 110,000 metric tons (100,000 tons) of toxic industrial wastes are illegally dumped into U.S. rivers each year, **(5)** fish caught in more than 1,400 different waterways are unsafe to eat because of high levels of pesticides and other toxic substances, **(6)** antiquated sewage systems in 1,100 cities still dump poorly treated sewage into streams, lakes, and coastal waters, **(7)** less than 2% of the country's 5.8 million kilometers (3.6 million miles) of streams are healthy enough to be considered high quality, **(8)** 40% of the country's surface and groundwater is unsafe for human use, and **(9)** a 2000 study by Friends of the Earth and the Environmental Working Group found that officials in all but seven states have allowed industrial water pollution permits to expire, effectively giving discharging industries an unlimited license to pollute.

Some environmentalists call for the Clean Water Act to be strengthened by **(1)** increasing funding and authority to control nonpoint sources of pollution, **(2)** increasing monitoring of state programs to see that pollution permits are not allowed to expire, **(3)** strengthening programs to prevent and control toxic water pollution, **(4)** providing more funding and authority for integrated watershed and airshed planning to protect groundwater and surface water from contamination, **(5)** permitting states with good environmental records to take over parts of the clean water program, under looser federal control, and **(6)** expanding the rights of citizens to bring lawsuits to ensure that water pollution laws are enforced.

Many people oppose these proposals, contending that the Clean Water Act's regulations are already too restrictive and costly. Farmers and developers **(1)** see the law as a curb on their rights as property owners to fill in wetlands and **(2)** believe that they should be compensated for property value losses because of federal wetland protection regulations (p. 589). State and local officials want more discretion in testing for and meeting water quality standards. They argue that in many communities it is unnecessary and too expensive to test for all the water pollutants required by federal law.

What Can We Do About Water Pollution from Point Sources? The Technological Approach As population, urbanization, and industrialization grow, the volume of wastewater needing treatment will increase enormously. In rural and suburban areas with suitable soils, sewage from each house usually is discharged into a **septic tank** (Figure 19-14). About 25% of all homes in the United States are served by septic tanks, which should be cleaned out every 3–5 years by a reputable contractor so that they will not contribute to groundwater pollution.

Figure 19-14 Septic tank system used for disposal of domestic sewage and wastewater in rural and suburban areas. This system traps greases and large solids and discharges the remaining wastes over a large drainage field. As those wastes percolate downward, the soil filters out some potential pollutants, and soil bacteria decompose biodegradable materials. To be effective, septic tank systems must be **(1)** properly installed in soils with adequate drainage, **(2)** not placed too close together or too near well sites, and **(3)** pumped out when the settling tank becomes full.



In urban areas, most waterborne wastes from homes, businesses, factories, and storm runoff flow through a network of sewer pipes to wastewater treatment plants. Some cities have separate lines for stormwater runoff, but in 1,200 U.S. cities the lines for these two systems are combined because it is cheaper. When rains cause combined sewer systems to overflow, they discharge untreated sewage directly into surface waters.

When sewage reaches a treatment plant, it can undergo up to three levels of purification. **Primary sewage treatment** is a *mechanical* process that uses screens to filter out debris such as sticks, stones, and rags and allows suspended solids to settle out as sludge in a settling tank (Figure 19-15). Improved primary treatment uses chemically treated polymers to remove suspended solids more thoroughly. By itself, primary treatment removes about 60% of the suspended solids and 30% of the oxygen-demanding organic wastes from sewage but removes no phosphates, nitrates, salts, radioisotopes, and pesticides.

Secondary sewage treatment is a *biological* process in which aerobic bacteria are used to remove up to 90% of biodegradable, oxygen-demanding organic wastes (Figure 19-15). Some treatment plants use *trickling filters*, in which aerobic bacteria degrade sewage as it seeps through a bed of crushed stones covered with bacteria and protozoa. Others use an *activated sludge process*, in which the sewage is pumped into a large tank and mixed for several hours with bacteria-rich sludge and air bubbles to facilitate degradation by microorganisms. The water then goes to a sedimentation tank, where most of the suspended solids and microorganisms settle out as sludge. The sludge produced by primary or secondary treatment is broken down in an anaerobic digester and **(1)** incinerated, **(2)** dumped into the ocean or a landfill, or **(3)** applied to land as fertilizer.

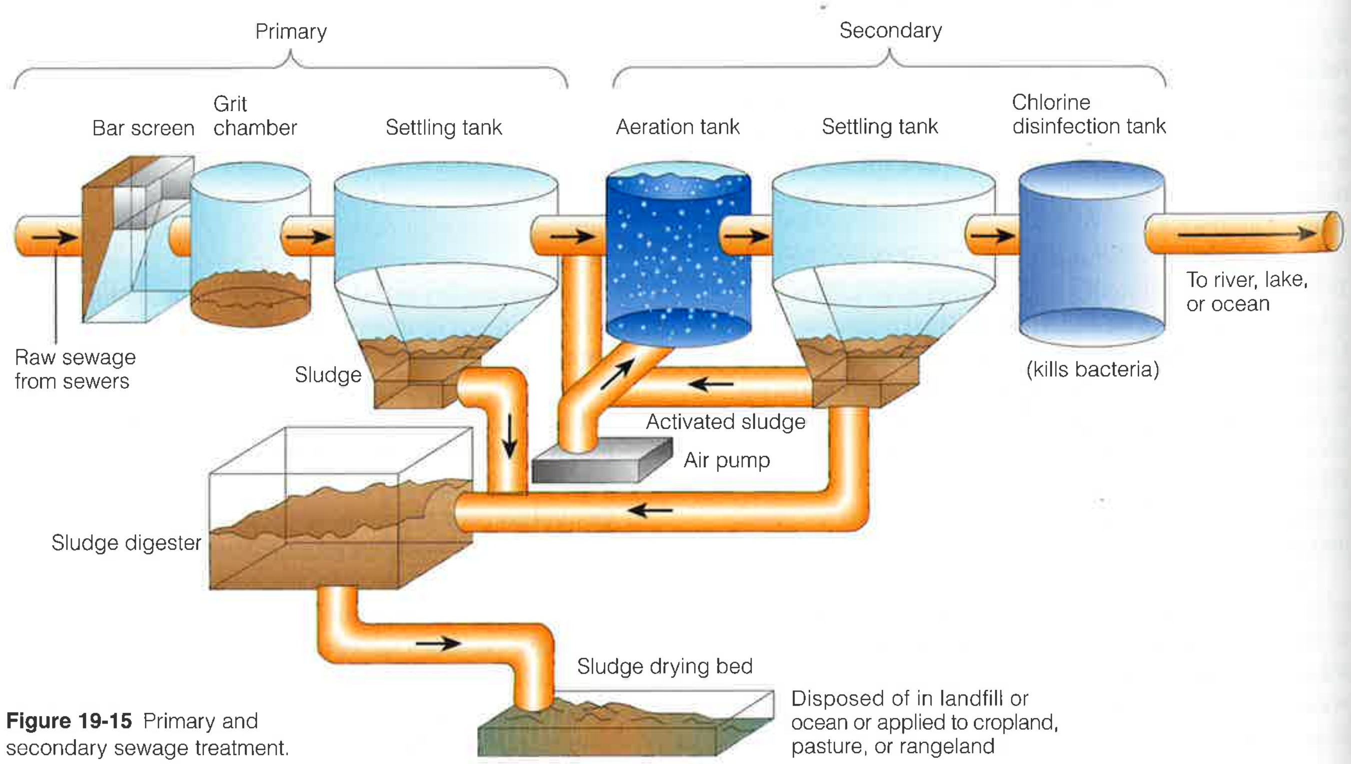


Figure 19-15 Primary and secondary sewage treatment.

A combination of primary and secondary treatment (Figure 19-15) removes about **(1)** 97% by weight of the suspended solids, **(2)** 95–97% of the oxygen-demanding organic wastes, **(3)** 70% of most toxic metal compounds and nonpersistent synthetic organic chemicals, **(4)** 70% of the phosphorus (mostly as phosphates), **(5)** 50% of the nitrogen (mostly as nitrates), and **(6)** 5% of dissolved salts. Almost no long-lived radioactive isotopes or persistent organic substances such as pesticides are removed.

As a result of the Clean Water Act, most U.S. cities have combined primary and secondary sewage treatment plants (Figure 19-15). However, government studies have found that **(1)** at least two-thirds of these plants have violated water pollution regulations, **(2)** 500 cities have failed to meet federal standards for sewage treatment plants, and **(3)** 34 East Coast cities simply screen out large floating objects from their sewage before discharging it into coastal waters.

Advanced sewage treatment is a series of specialized chemical and physical processes that remove specific pollutants left in the water after primary and secondary treatment (Figure 19-16). Advanced treatment is rarely used because such plants typically cost twice as much to build and four times as much to operate as secondary plants.

Before water is discharged after primary, secondary, or advanced treatment, it is bleached (to remove water coloration) and disinfected (to kill disease-carrying bacteria and some but not all viruses). The usual method for doing this is *chlorination*. However, chlorine can react with organic materials in water to form small amounts of chlorinated hydrocarbons, some of which cause cancers in test animals and may damage the human nervous, immune, and endocrine systems (Connections, p. 404). Use of other disinfectants, such as ozone and ultraviolet light, is increasing, but they cost more than chlorination and are not as long lasting.

What Should We Do with Sewage Sludge? Sewage treatment produces a toxic, gooey *sludge*. In the United States, about **(1)** 9% by weight is converted to compost for use as a soil conditioner and **(2)** 36% is applied to farmland, forests, golf courses, cemeteries, parkland, highway medians, and degraded land as fertilizer. The remaining 55% is **(1)** dumped in conventional landfills

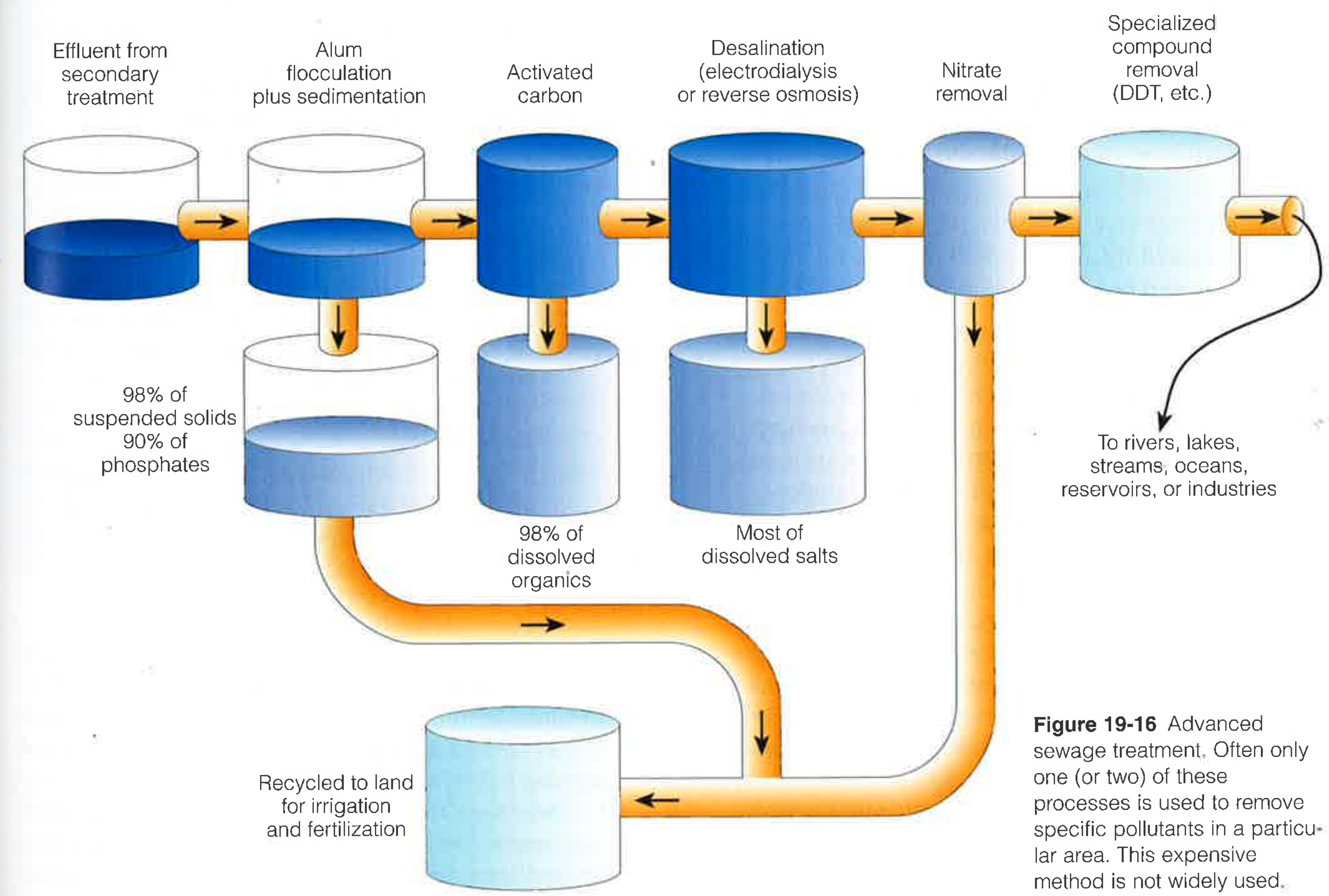


Figure 19-16 Advanced sewage treatment. Often only one (or two) of these processes is used to remove specific pollutants in a particular area. This expensive method is not widely used.

(where it can contaminate groundwater) or **(2)** incinerated (which can pollute the air with traces of toxic chemicals and produces a toxic ash, which usually is buried in landfills that EPA experts say will leak eventually).

From an environmental standpoint, it is desirable to recycle the plant nutrients in sewage sludge to the soil on land not used to grow food crops. As long as harmful bacteria and toxic chemicals are not present or are removed, sludge can also be used to fertilize land used for food crops or livestock. However, removing bacteria (usually by heating), toxic metals, and organic chemicals is expensive and is rarely done in the United States.

A growing number of health problems and lawsuits have resulted from use of sludge to fertilize crops in the United States. To protect consumers and avoid lawsuits, some food packers such as DelMonte and Heinz have banned produce grown on farms using sludge as a fertilizer. Also, farm credit bureaus are refusing to finance farms that use sludge because of the financial risks from contaminated soils.

Environmental scientist Peter Montague (Guest Essay, p. 526) believes that the entire sewage treatment approach should be redesigned with the goal of preventing toxic and hazardous waste from reaching sewage treatment plants. This would be accomplished by:

- Requiring industries and businesses to remove all toxic and hazardous wastes from water sent to municipal sewage treatment plants.
- Encouraging or requiring industries to reduce or eliminate toxic chemical use and waste through clean production (Guest Essay, p. 526, and Solutions, p. 525).
- Encouraging the use of less harmful household chemicals (Table 21-1, p. 521) and having harmful chemicals picked up and disposed of safely on a regular basis as part of garbage collection services.
- Having households, apartment buildings, and offices eliminate sewage outputs by switching to modern composting toilet systems that are installed, maintained, and managed by professionals. Such systems would be cheaper than current sewage systems because they do not require vast systems of underground pipes connected to centralized sewage treatment plants and conserve large amounts of water.

Using Wetlands to Treat Sewage

SOLUTIONS

Waste treatment is one of the important ecological services provided by wetlands. More than 600 cities, towns, and industries in the United States now use natural and artificial wetlands to treat sewage as a low-tech, low-cost alternative to expensive waste treatment plants.

Some communities have created artificial wetlands to treat their water, as the residents of Arcata, California, did, led by Humboldt State University professors Robert Gearheart and George Allen.

In this coastal town of 17,000, some 63 hectares (155 acres) of wetlands has been created between the town and the adjacent Humboldt Bay. The marshes, developed on land that was once a dump, act as an inexpensive, natural waste treatment plant. The project cost less than half the estimated cost of a conventional treatment plant.

Here's how it works: First, sewage is held in sedimentation tanks, where the solids settle out as sludge that is removed and processed for use as fertilizer. The liquid is pumped into oxidation ponds, where remaining wastes are broken down by bacteria. After a month or so, the water is released into the artificial marshes, where it is further filtered and cleansed by plants and bacteria.

Although the water is clean enough to be discharged directly into the bay, state law requires that it first be chlorinated. The town chlorinates the water and then dechlorinates it before sending it into the bay, where oyster beds thrive.

The marshes and lagoons also serve as an Audubon Society bird sanctuary and provide habitats for thousands of otters, seabirds, and marine animals. The town even celebrates its natural sewage treatment system with an annual "Flush with Pride" festival.

Critical Thinking

List some possible drawbacks to creating artificial wetlands to treat sewage. Do these drawbacks outweigh the benefits? Explain.

How Can We Treat Sewage by Working with Nature? Some communities and individuals are seeking better ways to purify contaminated water by working with nature (p. 476 and Solutions, above). Mark Nelson, who spent 2 years inside the Biosphere 2 facility in Arizona (p. 740), has developed a small, low-tech, and inexpensive artificial wetland system to treat raw sewage from hotels, restaurants, and homes in developing countries (Figure 19-17). This *wastewater garden* system removes 99.9% of fecal coliform bacteria and more than 80% of the nitrates and phosphates from incoming sewage that in most developing countries is often dumped untreated into the ocean or into shallow holes in the ground. The water flowing out of such systems can be used to irrigate gardens or fields or for flushing toilets and thus helps save water.

Another promising new technology for processing domestic sewage in developing countries is a *double-vault treatment system*. In this approach, human wastes and organic kitchen wastes are deposited in one chamber and later moved to a second chamber, where they are allowed to compost for several months. Solar heating and bacteria convert the waste in the second chamber into a safe and odorless soil conditioner that can be used on household gardens or sold to nearby farms. When the soil conditioner is removed, the wastes stored into the first holding chamber are transferred to the composting chamber. Such dry composting units use no water and are small enough to serve one or two families.

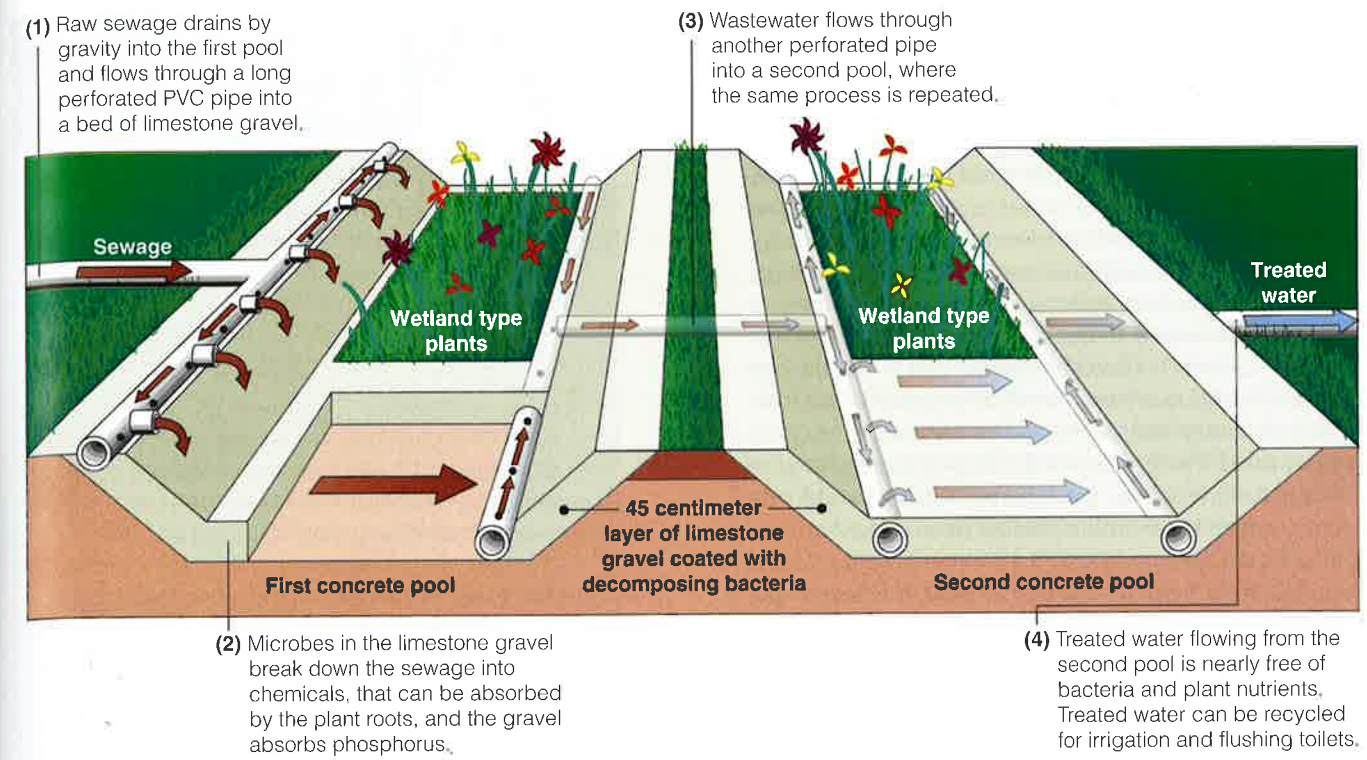


Figure 19-17 *Wastewater garden.* This small, artificial, gravity-fed wetland system for treating sewage from hotels, restaurants, and homes in developing countries was developed by the creators of the Biosphere 2 facility in Arizona (p. 740). This wastewater treatment system uses only 1.9–3.8 square meters (20–30 square feet) of space per person.

Other double-vault units are neighborhood mini-plants that biologically process the wet or water-flushed wastes of up to 1,000 people. These systems separate gray water from sewage and percolate the water through a bed of sand and gravel until it is pure enough to be used on gardens or to irrigate flowers, grass, or trees. Such systems typically cost one-seventh as much as a conventional sewer and waste treatment plant system and can produce fertilizer that can be sold to recoup the startup costs.

In addition to *living machine* sewage treatment systems (p. 476), scientists at Living Technologies have developed neighborhood-level *sewage walls* that would run along the length of a residential block. Sewage would be channeled through a series of four terraced planters that progressively filter and purify the waste. Each planter would be capped with glass to allow use of sunlight and contain the bacteria and plants best suited for the various stages of treatment. The resulting effluent could be used on local gardens, and the plants could be harvested periodically and converted to compost for use on neighborhood gardens.

Another approach is to use wastewater to grow forests. While the trees are growing, this approach can also remove carbon dioxide from the atmosphere and help slow global warming.

19-6 DRINKING WATER QUALITY

Is the Water Safe to Drink? About one-fourth of people in developing countries do not have access to clean drinking water. In China, an estimated 700 million people drink contaminated water, and only 6 of China's 27 largest cities provide drinking water that meets government standards. Contaminated drinking water is considered a key factor in the doubling of liver disease and cancer deaths in China since 1970. In Russia, half of all tap water is unfit to drink, and a third of the aquifers are too contaminated for drinking purposes. About 290 million Africans—about equal to the entire U.S. population—do not have access to safe drinking water.

In many poor villages in developing countries, people get their water from **(1)** shallow groundwater wells that are easily contaminated, **(2)** nearby polluted river water, or **(3)** mudholes used by both animals and humans.

In most urban slums in developing countries, drinking water is not pumped in or the poor there cannot afford a house connection. Such poor urban dwellers must either **(1)** drink contaminated water from rivers or other sources or **(2)** buy it from street vendors at an average cost of 12 times more per liter than middle-class families pay for water piped to their houses. A 1999 study by the World Commission on Water for the 21st Century found that much of the water sold by urban street vendors is drawn from polluted rivers or other contaminated sources.

The United Nations estimates that it would cost about $25 billion a year over 8–10 years to bring low-cost safe water and sanitation to the 1.4 billion people—one of every four—who do not have access to clean drinking water. These expenditures could prevent many of the 5 million deaths (including 2 million children under age 5) and 3.4 billion cases of illness caused each year by unsafe water. Currently, the world is spending only about $8 billion a year on clean water efforts. The $17-billion shortfall is about equal to what people in Europe and the United States spend each year on pet food or about what the world spends every 8 days for military purposes. Researchers are trying to find cheap and simple ways to purify drinking water in developing nations (Individuals Matter, right).

How Is Drinking Water Purified? Treatment of water for drinking by city dwellers is much like wastewater treatment. Areas that depend on surface water usually store it in a reservoir for several days to improve clarity and taste by allowing the dissolved oxygen content to increase and suspended matter to settle out. The water is then pumped to a purification plant, where it is treated to meet government drinking water standards. Usually the water is run through sand filters and activated charcoal before it is disinfected. In areas with very pure groundwater sources, little treatment is necessary.

How Is the Quality of Drinking Water Protected? About 54 countries, most of them in North America and Europe, have safe drinking water standards. The U.S. Safe Drinking Water Act of 1974 requires the EPA to establish national drinking water standards, called *maximum contaminant levels*, for any pollutants that may have adverse effects on human health.

Privately owned wells are not required to meet federal drinking water standards, primarily because of the costs of testing each well regularly (at least $1,000) and opposition to mandatory testing and compliance by some homeowners.

It is difficult to estimate how many people in the United States get sick or die each year from drinking

Using UV Light, Horseradish, and Slimes to Purify Water

INDIVIDUALS MATTER

Ashok J. Gadgil, a physicist at California's Lawrence Berkeley National Laboratory, and his colleagues have recently developed a simple device that uses ultraviolet light to kill disease-causing organisms in drinking water. When water from a well or hand pump (in a village or household in a developing country) is passed through this tabletop system, UV radiation from a mercury vapor lamp zaps germs in the water.

This $300 device weighs only 7 kilograms (15 pounds) and can disinfect 57 liters (15 gallons) of water per minute at a very low cost. It draws only 40 watts of power, supplied by solar cells, and can run unsupervised in remote areas of developing countries.

Recently, Pennsylvania State soil biochemists discovered that chopped horseradish mixed with hydrogen peroxide (H_2O_2) helps rid contaminated water of organic pollutants called *phenols*. The horseradish contains an enzyme that speeds up the breakdown of the phenols.

Judith Bender and Peter Phillips at Clark Atlanta University in Georgia have found a way to use slime produced by cyanobacteria to decompose chlorinated hydrocarbons that contaminate drinking water. Within 3 weeks, a slimy, floating bacterial mat can surround and decompose a glob of toxic chlordane (a pesticide banned in the United States as a suspected carcinogen). Such slime mats can also remove lead, copper, chromium, cadmium, selenium, and other toxic metals from water.

contaminated water. Estimates include **(1)** 7 million illnesses and 1,200 deaths per year according to a 1994 study by the Natural Resources Defense Council, **(2)** 1 million illnesses and about 900 deaths according to a 1997 report by the Centers for Disease Control and Prevention, and **(3)** 239,000 illnesses and 50 deaths according to a 1999 EPA study.

In April 1993, a dramatic incident occurred when residents of Milwaukee, Wisconsin, were told that water from their taps was unsafe to drink. Before this health crisis was over, 111 people had died and 403,000 people had become sick as a result of exposure to *Cryptosporidium*, a parasitic organism. Milwaukee spent an estimated $54 million to deal with this outbreak. In May 1994, another outbreak of this parasite killed 19 and sickened more than 100 people in Las Vegas, Nevada.

After these incidents, the EPA stepped up efforts to require public water systems to detect and prevent contamination by disease-causing pathogens such as *E. coli* and *Cryptosporidium* in drinking water obtained from surface sources such as lakes and rivers. In 2000, the EPA proposed new rules that would require public water systems getting all or part of their water from underground aquifers to monitor more closely for such organisms and use disinfectants if such threats are found. According to the EPA, these new regulations are expected to prevent more than 115,000 illnesses a year.

In 1999, an EPA audit found that communities and states were not reporting about 88% of all violations of the Safe Drinking Water Act to the government database used to alert consumers and trigger legal actions when water systems do not meet health standards. These violations range from missed water quality tests to contamination problems.

According to the Natural Resources Defense Council (NRDC), U.S. drinking water supplies could be made safer at a cost of only about $30 a year per household. However, Congress is being pressured by water-polluting industries to weaken the Safe Drinking Water Act by **(1)** eliminating national tests of drinking water, **(2)** eliminating the requirement that the media be advised of emergency water health violations and that water system officials notify their customers of such violations, **(3)** allowing states to give drinking water systems a permanent right to violate the standard for a given contaminant if the provider claims it cannot afford to comply, and **(4)** eliminating the requirement that water systems use affordable, feasible technology to remove cancer-causing contaminants.

Environmentalists call for the U.S. Safe Drinking Water Act to be strengthened by **(1)** improving treatment by combining at least half of the 50,000 water systems that serve fewer than 3,300 people each with larger ones nearby, **(2)** strengthening and enforcing public notification requirements about violations of drinking water standards, and **(3)** banning all lead in new plumbing pipes, faucets, and fixtures (current law allows fixtures with up to 10% lead to be sold as lead-free).

Is Bottled Water the Answer? Despite some problems, experts say that the United States has some of the world's cleanest drinking water. Yet about half of all Americans worry about getting sick from tap water contaminants, and many drink bottled water or install expensive water purification systems. Studies indicate that many of these consumers are being ripped off and in some cases may end up drinking water that is dirtier than water they can get from their taps.

An estimated one-third of the bottled water purchased in the United States is contaminated with bacteria. To be safe, consumers purchasing bottled water should determine whether the bottler belongs to the International Bottled Water Association (IBWA) and adheres to its testing requirements.* Some companies pay $2,500 annually to obtain more stringent certification by the National Sanitation Foundation, an independent agency that tests for 200 chemical and biological contaminants.

Before drinking expensive bottled water and buying costly home water purifiers, health officials suggest that consumers have their water tested by local health authorities or private labs (not companies trying to sell water purification equipment) to **(1)** identify what contaminants, if any, must be removed and **(2)** recommend the type of purification needed to remove such contaminants. Independent experts contend that unless tests show otherwise, for most urban and suburban Americans served by large municipal drinking water systems, home water treatment systems are not worth the expense and maintenance hassles.

Buyers should carefully check out companies selling water purification equipment and be wary of claims that the EPA has approved a treatment device. Although the EPA does *register* such devices, it neither tests nor approves them.

How Can We Reduce Water Pollution? An Integrated Approach According to environmentalists, a sustainable approach to dealing with water pollution requires that we shift our emphasis from pollution cleanup to pollution prevention by **(1)** *reducing* the toxicity or volume of pollutants (for example, replacing organic solvent-based inks and paints with water-based materials), **(2)** *reusing* wastewater instead of discharging it (for example, reusing treated wastewater for irrigation), and **(3)** *recycling* pollutants (for example, cleaning up and recycling contaminated solvents for reuse) instead of discharging them.

To make such a shift, we need to accept that the environment—air, water, soil, and life—is an interconnected whole. Without an integrated approach to all forms of pollution, environmentalists argue that we will continue to shift environmental problems from one part of the environment to another. Some actions you can take to help reduce water pollution are listed in Appendix 6.

It is a hard truth to swallow, but nature does not care if we live or die. We cannot survive without the oceans, for example, but they can do just fine without us.

Roger Rosenblatt

*Check for the IBWA seal of approval on the bottle or contact the International Bottled Water Association (113 North Henry Street, Alexandria, VA 22314; phone: 703-683-5213) for a member list.

REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Describe John Todd's *living machines* used to purify sewage.

3. What is *water pollution*? Describe how a *coliform bacteria count*, measurement of *biological oxygen demand*, and *biological indicators* can be used to determine water quality. What are eight types of water pollutants, and what are the major sources and effects of each type?

4. Distinguish between *point* and *nonpoint sources of water pollution* and give two examples of each type. Which type is easier to control? Why?

5. What are the major water pollution problems of streams? Explain how streams can handle some loads of biodegradable wastes, and explain the limitations of this approach.

6. Summarize the good and bad news about attempts to prevent or control stream pollution.

7. What are the major water pollution problems of lakes? Distinguish between *eutrophication* and *cultural eutrophication*. What are the major causes of cultural eutrophication? List three methods for **(a)** preventing cultural eutrophication and **(b)** cleaning up cultural eutrophication.

8. Summarize the good and bad news about attempts to reduce water pollution in the Great Lakes.

9. Explain how climate change from projected global warming can decrease the quality of surface water.

10. List five major sources of groundwater contamination. List three reasons why groundwater pollution is such a serious problem.

11. List five examples indicating the seriousness of groundwater pollution. List four ways to prevent groundwater contamination.

12. List the major pollution problems of the oceans. Why are most of these problems found in coastal areas?

13. Describe the ocean pollution problems caused by large inputs of plant nutrients from river systems.

14. Summarize the major pollution problems of the Chesapeake Bay in the United States and the progress made in dealing with these problems.

15. Distinguish between ocean pollution from *dredge spoils* and from *sewage sludge*. Distinguish between *crude petroleum* and *refined petroleum* and summarize the major water pollution problems caused by oil. What are the three major sources of oil pollution in the world's oceans? List six ways to help prevent oil pollution of the oceans and two ways to help clean up such pollution.

16. List six ways to help prevent water pollution from nonpoint sources. Why has there been so little emphasis on dealing with this problem?

17. Explain how the United States and most developed countries have reduced water pollution from point sources by enacting laws, and summarize the good and bad news about such efforts. List six ways in which environmentalists believe water pollution control laws in the United States should be strengthened, and list two reasons why there is opposition to such changes.

18. Distinguish between *septic tanks*, *primary sewage treatment*, *secondary sewage treatment*, and *advanced sewage treatment* as ways to reduce water pollution. List ways to deal with the sludge produced by waste treatment methods. What are the pros and cons of each approach?

19. Describe three ways to treat sewage based on working with nature.

20. What percentage of the world's people does not have access to clean drinking water? About how many children under age 5 die each year from infectious diseases caused by drinking contaminated water?

21. How is drinking water purified? How is the quality of drinking water protected in the United States? How successful have these efforts been? List three ways in which environmentalists believe the U.S. Safe Drinking Water Act should be strengthened and four ways in which opponents believe it should be weakened. List the pros and cons of drinking bottled water.

22. List three ways to shift the emphasis from cleanup to prevention of water pollution.

CRITICAL THINKING

1. Why is dilution not always the solution to water pollution? Give examples and conditions for which this solution is or is not applicable.

2. How can a stream cleanse itself of oxygen-demanding wastes?-Under what conditions will this natural cleansing system fail?

3. Which of the eight categories of pollutants listed in Table 19-1 are most likely to originate from **(a)** point sources and **(b)** nonpoint sources?

4. A large number of fish are found floating dead on a lake during the summer. You are called to determine the cause of the fish kill. What reason would you suggest for the kill? What measurements would you make to verify your hypothesis?

5. Explain why a number of communities around the Great Lakes have banned the use of phosphate-containing detergents in recent years.

6. Should injection of liquid hazardous wastes into deep wells below drinking water aquifers (Figure 19-9) be banned? Explain. What are the alternatives?

7. Explain why some health officials project that groundwater pollution could be one of the world's most serious health problems between 2050 and 2100.

8. Should all dumping of wastes and untreated sewage in the ocean be banned? Explain. If so, where would you put the wastes instead? What exceptions would you permit, and why? How would you enforce such regulations?

9. Your town (Town B) is located on a river between towns A and C. What are the rights and responsibilities of upstream communities to downstream communities? Should sewage and industrial wastes be dumped at the upstream end of a community that generates them?

10. Congratulations. You have been placed in charge of sharply reducing nonpoint water pollution throughout the world. What are the three most important things that you would do?

11. Congratulations. You have been placed in charge of sharply reducing groundwater pollution throughout the world. What are the three most important things you would do?

PROJECTS

1. In your community,
   a. What are the principal nonpoint sources of contamination of surface water and groundwater?
   b. What is the source of drinking water?
   c. How is drinking water treated?
   d. How many times during each of the past 5 years have levels of tested contaminants violated federal standards? Was the public notified about the violations?
   e. Is fishing prohibited in any lakes or rivers in your region because of pollution? Are people warned about this?
   f. Is groundwater contamination a problem? If so, where, and what has been done about the problem?
   g. Is there a vulnerable aquifer or critical recharge zone that should be protected to ensure the quality of groundwater? Is your local government aware of this? What action (if any) has it taken?

2. Are storm drains and sanitary sewers combined or separate in your area? Are there plans to reduce pollution from stormwater runoff? If not, make an economic evaluation of the costs and benefits of developing separate storm drains and sanitary sewers, and then present your findings to local officials.

3. Arrange a class or individual tour of a sewage treatment plant in your community. Compare the processes it uses with those shown in Figure 19-15. What happens to the sludge produced by this plant? What improvements, if any, would you suggest for this plant?

4. Use library research, the internet, and user interviews to evaluate the relative effectiveness and costs of home water purification devices. Determine the type or types of water pollutants each device removes and the effectiveness of this process.

5. Use the library or the internet to find bibliographic information about *William Ruckelshaus* and *Roger Rosenblatt*, whose quotes appear at the beginning and end of this chapter.

6. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface). Look at the inside back cover and on the website for this book for information about making concept maps.

INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to:

http://www.brookscole.com/product/0534376975s

and click on the Chapter-by-Chapter area. Choose Chapter 19 and select a resource:

- "Flash Cards" allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
- "Tutorial Quizzes" provides a multiple-choice practice quiz.
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- "References" lists the major books and articles consulted in writing this chapter.
- "Hypercontents" takes you to an extensive list of sites with news, research, and images related to individual sections of the chapter.

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1999. Watershed management is key to improving America's water resources. *Journal of Environmental Health* vol. 61, no. 9, pp. 43–44. (subject guide: water quality, standards)

Kreeger, K. 2000. Down on the fish farm: developing effluent standards for aquaculture. *BioScience* vol. 50, no. 11, pp. 949–953. (keywords: aquaculture, effluent)